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NAME OF AUTHOR YVES GIROUARD

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ENCODING AND RECOGNITION CHARACTERISTICS OF DIFFERENT MOVEMENT CUES REVEALED BY RECOGNITION-MEMORY EXPERIMENTS

by

© YVES GIROUARD

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Encoding and retention characteristics of different movement cues revealed by recognition-memory experiments," submitted by Yves Girouard in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Abstract

Motor recognition memory was studied in a situation in which Ss had to decide whether or not a test movement, or some of its features, was part of a previously memorized set of movements. Simple linear positioning movements were analyzed and recognition latency was used as the main dependent variable. Four movement features or cues were compared: starting location, end location, distance, and distance-plus-location (i.e. the movement as a whole). In Experiment I, the factor of interest was memory set size. In Experiment II, the comparison was made between indicating the feature to be recognized before and after the presentation of the to-be-memorized movement. Three different retention intervals were compared in Experiment III: immediate recognition, recognition after a 20 sec unfilled, and after a 20 sec retention interval filled with an attention-demanding task. Recognition errors were found to be a linear function of memory set size. Furthermore, increase in errors was due to an increase in false positive errors as a function of set size. There were no differences between the two loci of cuing in as far as recognition errors were concerned. Distance and end location information displayed identical encoding characteristics as indexed by recognition errors and also displayed identical encoding and retention characteristics as indexed by recognition latencies: recognition latencies were unaffected until rehearsal was prevented by the interpolated task for both cues.

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Table of Contents

CHAPTER		PAGE
I.	STATEMENT OF THE PROBLEM	1
	Introduction	1
	Need for the study	3
	The problem	5
	Definitions	7
II.	REVIEW OF LITERATURE	9
	Cue effects in movement reproduction	9
	E-defined movement	10
	S-defined movement	17
	Studies on motor recognition	21
	A complementary approach: recognition memory latencies	24
	Retention interval effects	35
	Translation effects	36
	Positive versus negative responses	37
	Controversies about this paradigm	38
	Encoding and recognizing movement information	40
III.	GENERAL METHOD	49
IV.	METHOD, RESULTS AND DISCUSSION	53
	Experiment I	53
	Method	53
	Results	57
	Discussion	70

Experiment II 74
Method 74
Results 76
Discussion 78
Experiment III 84
Method 84
Results 87
Discussion 91
V. GENERAL DISCUSSION AND CONCLUSIONS 97
General discussion 97
Conclusions 102
BIBLIOGRAPHY 105
APPENDIX A. STIMULUS MATERIAL 116
APPENDIX B. INSTRUCTION TO THE SUBJECTS 122
APPENDIX C. COMPLEMENTARY DATA AND ANALYSES 125

List of Tables

Tables Page

1. Summary of the analysis of variance on the error scores of Experiment I 58

2. Mean percent of errors for each memory set size as a function of the responses required 60

3. Mean percent of errors for each movement cue as a function of movement length categories 64

4. Summary of the analysis of variance on the reaction-time data of Experiment I 66

5. Mean reaction time (in msec) as a function of movement cue for each type of response 68

6. Summary of the analysis of variance on the error scores of Experiment II 77

7. Mean percent of errors for each movement cue as a function of the loci of instructions and the responses required . . 79

8. Summary of the analysis of variance on the reaction-time data of Experiment II 80

9. Mean reaction time (in msec) for each movement cue as a function of the loci of instructions and the responses required 81

10. Summary of the analysis of variance on the error scores of Experiment III 88

11. Mean percent of errors for each retention interval condition as a function of the movement cues and the responses required 89

12. Summary of the analysis of variance on the reaction-time data of Experiment III 92

13. Mean reaction time (in msec) for each retention interval condition as a function of the movement cues and the responses required 93

14. Stimulus material for Experiment I 117

15. Stimulus material for Experiment II 119

16. Stimulus material for Experiment III 120

17. Linear trend analyses of recognition errors as a function of memory set size (Experiment I) 126

18. Linear trend analysis of recognition reaction time as a function of memory set size (Experiment I) 126

19. Tukey (a) tests applied to differences between means of percent recognition errors for memory set size and movement cues (Experiment I) 127

20. Tukey (a) tests applied to differences between means of percent recognition errors for movement cues (Experiment II) 128

21. Tukey (a) tests applied to differences between means of recognition reaction-time for the retention interval conditions (Experiment III) 129

List of Figures

Figure		Page
1.	Relationship between perceptual and conceptual codes in a memory-search task	43
2.	Flowchart representing the memory and decision stages involved in recognition	47
3.	View of subject and apparatus	51
4.	Mean percent of false positive and false negative errors as a function of memory set size	62
5.	Mean reaction time for positive and negative responses as a function of memory set size	67
6.	Mean reaction time as a function of memory set size for each movement cue	69
7.	Mean percent of false negative and false positive errors as a function of retention intervals	90

Chapter 1

STATEMENT OF THE PROBLEM

Introduction

A fairly large number of research papers have now been published on short-term motor memory (STMM) as it is evidenced in recent reviews on this topic (Gentile, 1974; Stelmach, 1974; Marteniuk, 1975a). One feature of all these studies conducted up to now with one exception (Marshall, 1972), is the use of the motor recall paradigm whereby a subject (S) is asked to reproduce a movement previously executed in a one-trial learning. Early findings (Posner, 1967b; Williams, Beaver, Spence & Rundell, 1969) indicated that kinesthetic information were spontaneously forgotten over unfilled retention intervals and this was taken as evidence that such information were not centrally codable.

Posner (1967a) for example, proposed that kinesthetic information was directly represented in STMM, which was a direct analogy with the visual information stored in a short-term sensory storage system. In that type of storage system the information is readily available for a brief period of time in its physical characteristics. That is, it is available prior to any transformation performed on it (Sperling, 1967). As described by Posner (1967a): "the kinesthetic image would be a relatively direct representation of the stimulus which might include spatial position and other detailed information which would not appear in a verbal description of the stimulus" (p. 268). In this sense

therefore, kinesthetic information would not be centrally codable but would be directly represented in STMM. Although in this instance Posner (1967a) used the terms "kinesthetic image", he preferred the terms "kinesthetic code". In a subsequent publication (Posner, 1967b) he used that term because he thought that the word "image" could be too easily confused with the concepts of visual image and imagery.

Keele (1973) adopted a very similar point of view. He reviewed a selective number of papers on STMM and concluded that the information first thought to be stored in STMM, would in fact be stored in a sort of kinesthetic sensory register. That information would be directly represented in the register and would not need any internal transformation processes. Further, that information would be available for recall for a period of approximately 20 sec.

However it appears very difficult to disregard encoding processes as an inherent feature of the motor memory system, due to the fact that such processes are central to any information processing approach. As Newell (1972) said:

> "As soon as one proposes to design an information processing system to accomplish any of the tasks studied, say in the psychology of learning, then the issue of representing the stimulus and the encoding operations to map the stimulus into its internal representation are forced to center stage". (p. 392)

In fact, later studies (Wilberg, 1969; Pepper & Herman, 1970) showed that sometimes, retention of kinesthetic information requires attention during a retention interval in order to be correctly recalled. Laabs (1971) suggested that whether or not kinesthetic information will spontaneously decay could be explained by reference to the movement cues upon which motor recall is based, and advocated the separation and independent manipulation of movement cues. Laabs (1971) showed that in fact, distance information was spontaneously

forgotten whereas end-location of a movement was easily retained over an unfilled retention interval. Laabs' work (1971) initiated a period during which a great number of studies were conducted on cue effects in STMM. As will be seen in details in the next chapter, Laabs' results were substantiated and generalized by several researchers: distance information does appear to have different encoding and retention characteristics relative to end-location information. This implies that different retention functions could be explained, at least partly, on the basis of the movement cue dimensions along which Ss encoded kinesthetic information.

Need for the study

While the recall paradigm has led to an accumulation of knowledge about how an individual recalls when his attention is selectively directed to one cue, the literature mentions very little about how the original to-be-reproduced movement was internally represented. This raises the fundamental question of "what is stored when the original movement is executed?" For example, if S is not pre-cued to attend to any one particular cue while executing the to-be-reproduced movement, will he be able to reproduce extent as well as end-location information? Moreover, if Ss have difficulties in encoding and retaining distance information, will they have more difficulties in recognizing distance information than they will have in recognizing end-location information?

The last question points to a relatively unexplored area of STMM: recognition of kinesthetic information. The present series of experiments will therefore address this question by using a recognition rather than a recall paradigm. Three reasons are offered in support of

this choice. One, because recognition is a major learning task *per se* and deserves to be studied (Kausler, 1974). Two, because there is a need for a better understanding of the recognition processes in motor performance, particularly in lights of recent models of motor recall (Adams, 1971; Pew, 1974; Schmidt, 1975) that have postulated a recognition mechanism which would give S the capability of comparing and evaluating the quality of a given movement with reference to the correct, stored movement. Three, because a recognition paradigm can be particularly sensitive to encoding and storage processes (Kintsch, 1970; McCormack, 1972).

Concerning the second reason, Adams (1971) for example, has postulated the presence of two distinct mechanisms that would be responsible for the accurate reproduction of simple linear positioning movements. The first mechanism would be responsible for the selection and initiation of the response at the time of recall. The second mechanism would be responsible for the comparison between response-produced feedback of the ongoing movement with a stored representation of the correct, criterion movement. If a successful comparison is made, with the feedback from the current response matching the criterion, the response is considered correct. If a successful match is not made and S senses an error signal, S will act in response to the error signal by giving a new error-correcting response. In this view therefore, recall is seen fundamentally as a recognition process whereby the current, ongoing movement is compared to a criterion movement and any discrepancy is analyzed as an error. In other words, an important process in motor performance seems to be the capability of recognizing a movement as the correct one (Newell, 1976). However Adams' closed-loop

theory (1971) as well as others (Pew, 1974; Schmidt, 1975) are quite silent on the processes involved in such recognition, with the exception of the postulated quality and quantity of the response-produced feedback (Marshall, 1972). Moreover, no studies are available which would have analyzed differential movement cue effects in motor recognition memory.

The problem

The purpose of this series of experiments is therefore to investigate the encoding and memory characteristics of different movement cues as revealed by recognition latencies. Such dependent variable has been used in a wide variety of experimental conditions in perceptual and verbal memory (Sternberg, 1969a; Nickerson, 1973; Westcourt & Atkinson, 1976) and it was felt that it was a valid measure for the processes at hand. However, it must be pointed out that the purpose of this series of experiments is not to extend or generalize a particular model of recognition latencies (e.g. Sternberg's model of the different stages involved in such a measure) to the class of information comprised by kinesthetic information. The procedure is rather to use total recognition latencies, as opposed to fractionated latencies, as indicators of the processes involved in the recognition of the different movement cues (Taylor, 1976, p. 183).

Therefore, the following research was an effort to separate three of the more prominent, general cues found in simple linear positioning movement, namely: (a) movement starting-location, (b) movement end-location, and (c) movement distance and to investigate their recognition characteristics. In the recognition task that was investigated, S had to decide whether or not a given test movement (or one of its cue)

was a member of a predefined set of memory items. For any ensemble of movements, movements in one subset were defined as memory items while the movements in the other subset were defined as distractor items. The experimental task involved a series of discrete trials with a movement selected from the ensemble presented on each trial. To each presentation, S made either a positive response by pressing one of two keys or a negative response by pressing the other key, indicating that he judged the test movement to be a memory or a distractor item, respectively.

The specific purposes of each experiments were as follows.

Experiment I: the purpose of the first experiment was twofold. One, to see if recognition latencies were the same for the three types of movement cues namely: (a) starting location, (b) end location, and (c) distance. Two, to see if recognition latencies of the three movement cues were similarly affected by the number of movements in the memory set.

Experiment II: the purpose was to compare the effects of two cuing conditions on the recognition latencies of movement cues: (a) a precuing condition in which S knows before memorizing the criterion movement which cue will have to be recognized later on, and (b) a post-cuing condition in which S knows only after having memorized the cirterion movement which cue will have to be recognized later on.

Experiment III: the purpose was to determine the memory effects on recognition latencies of movement cues by manipulating the length of the retention interval, and the availibility of attention during the retention interval.

A more elaborate rational that supports each experiment, along with the literature behind it will be presented in the next chapter. It was

felt that the three experiments would lead toward a better understanding of the recognition processes in STMM, and particularly of the encoding and memory characteristics of the different movement cues.

Definitions

Short-term memory. A memory system that rapidly loses information in the absence of sustained attention of that material. It is thought to involve the first 60 seconds following presentation of the information, after which it is either lost or transfered to long-term memory (Marteniuk, 1976, p. 85).

Encoding. The process by which an internal representation of a stimulus event is developed (Bower, 1967).

Kinesthesis. Sensory modality concerned with the conscious perception of movement and orientation of the parts of the body with respect to each other and with respect to the body as a whole (Howard & Templeton, 1966).

Distance information. Distance information or movement length is isolated when a test movement is started from a location different from the starting location of the criterion movement. Then, if S is told to recognize the distance of the criterion movement, location cues from the criterion movement become unreliable cues for the test movement.

Location information. In a similar manner, if S is told to recognize location information (either the starting or the end location of a movement), distance information is made an unreliable cue in the test movement by using a different distance relative to the one used for the criterion movement.

Recognition memory. This term covers of wide variety of phenomena in which the subject attempts to decide whether or not a given object or event (in this case: a movement cue) has been experienced before (Atkinson & Juola, 1974).

Recognition latency. At the end of any test movement, S will hit a physical stop to which a micro-switch will be attached. A timer will then be activated which will be stopped by having S to press one of two keys in order to express his response. The recognition latency (usually referred to as recognition reaction-time) is the time from termination of the test movement to S's key-pressing response.

Chapter 2

REVIEW OF LITERATURE

The review of literature has been divided into four sections leading from available evidence on movement cue effects in motor recall memory to a general theoretical framework that will allow meaningful interpretation of recognition latencies of movement cues. The order of presentation of the four sections are as follows: (a) cue effects in movement reproduction, (b) motor recall versus recognition, (c) recognition memory latencies, and (d) encoding and recognizing movement information.

Cue effects in movement reproduction

No studies are known to the author which would have compared encoding and retention characteristics of different movement cues in a memory recognition paradigm with reaction-time as the dependent variable. However, several studies have been realized on these issues concerning movement reproduction accuracy and a brief review of these studies is necessary at this point. Only those studies which have directly compared distance and location cues will be critically reviewed here.

Before beginning, two comments are necessary. First, a brief explanation of the dependent measures used in this paradigm. Usually, three different error scores are analyzed: the mean of the unsigned or absolute error (AE), the mean of the algebraic or constant error (CE),

and the standard deviation of the constant error, called variable error (VE) (Laabs, 1973). Since most studies reported here are recent and have used at least two of the dependent measures mentioned [with the exception of Posner (1967b) and Roy (1976)], no differential account of the various studies will be given, based on the different dependent measures that have been used. However when necessary, significant results will be reported in terms of the error scores that were used and this explains why those scores are defined here.

The second comment concerns the distinction between Experimenter-defined (E-defined) movement and Subject-defined (S-defined) movement. E-defined movement is one that is entirely determined by the E; that is to say, during the execution of the to-be-reproduced movement, S moves until he hits a physical stop placed by the E. On the other hand, S-defined movement is one in which S determines himself where and when to stop (of course, within reasonable limits determined by E). Since recent evidence suggest that this might represent a crucial variable which might help to explain discrepant results in the STMM literature (Marteniuk, 1973; Jones, 1974; Stelmach, Kelso & Wallace, 1975), the review will be divided into two parts: (a) studies which have used E-defined movement, and (b) studies which have used S-defined movement.

E-defined movement. An experiment by Posner (1967b) was the first to attempt to independently examine distance (D) and end-location (EL) cues. He examined kinesthetic (K) and kinesthetic plus visual (K+V) recall of D and EL information under three reproduction conditions: immediate, 20 sec rehearsal, and 20 sec filled with a mental classification task. Analysis of AE scores only, indicated the following: (a) although that immediate reproduction of K location tended to be

more accurate than K distance, the difference was not significant, (b) both K location and K distance were affected in the same ways by the two delayed reproduction conditions, namely forgetting occured even during the unfilled interval and was not further increased by the interpolated, attention-demanding task. Posner (1967b) was therefore led to conclude that K information (both D and EL information) was only affected slightly by the availability of attention during a retention interval; a fact contrary to that found for visual information. However results must be cautiously accepted for two reasons. One, because in all reproduction conditions the cue that was not being examined still offered reliable information (all conditions were D+L reproduction, one cue being emphasized by prior instruction). Second, by reporting only AE scores, effects represented in CE and VE scores may have been missed.

Marteniuk and Roy (1972) directly tested a presumed superiority of end location over distance information in an immediate reproduction condition. They had four independent groups of 10 Ss each with each group being assigned one of the four following treatment conditions: (a) D reproduction, (b) EL reproduction, (c) EL reproduction when the to-be-reproduced EL was presented with alternation passive movements, and (d) EL reproduction from different starting positions. Results reported were unambiguous in that all types of error scores (AE, CE, and VE) converged to the same findings: immediate reproduction of D information was significantly less accurate than each of the other three experimental conditions. Such findings suggest that the superiority of EL over D information was valid in spite of kinesthetic "noise" (alternation passive movements) induced during the execution of the movement toward the criterion EL and regardless of the

starting location. Results were interpreted as meaning that encoding of EL information was more precise than D information.

In the second of a series of three experiments, Marteniuk, Shields, and Campbell (1972) made a direct comparison between immediate reproduction of EL, D, and D+L information. Eighteen Ss performed 15 trials in each of the three reproduction conditions. Only one standard, angular, positioning movement was tested. Analyses of both AE and CE scores indicated significant differences for each type of error scores favoring each time a more accurate reproduction of EL relative to D information. Furthermore there were no difference between D+L and EL reproduction. The authors interpreted that finding as meaning that in the former case the Ss were coding movements based upon EL information.

Laabs (1973) conducted two experiments in which he compared the encoding and retention characteristics of D and EL information under three reproduction conditions: (a) immediate, (b) reproduction after 12 sec rehearsal, (c) reproduction after 12 sec interpolated activity. Analysis of VE scores under immediate reproduction showed that D and EL were equally well retained. However EL information could also be retained over an unfilled interval whereas D information decayed spontaneously. Due to the inability of the Ss to rehearse D information, inference was made that D was not codable. Furthermore the interpolated mental activity which blocked rehearsal, produced strong interference effect on the retention of EL information but little effect on the retention of D information over that produced by decay. Laabs' conclusion according which D and EL information have different encoding and retention characteristics appeared warranted.

Laabs (1974) partially replicated the findings of his first experiments when compared again the retention characteristics of D and EL location between a 20 sec rehearsal condition and a 20 sec filled retention interval condition. The latter was filled with movements either longer or smaller than the to-be-reproduced movements. The interpolated movement which did not have to be remembered did not cause interference with the retention of EL information but did cause interference with the retention of D information thereby replicating Laabs' earlier findings (1973). On the other hand, using VE as the index of forgetting he found EL reproduction stable over time while forgetting of D information was restricted to large movements only [in the previous experiment (Laabs, 1973), D information from all movement extents manifested spontaneous decay].

EL codes and D+L codes were compared by Keele and Ells (1972) in a factorial design involving several factors under which the two codes were tested. The factors were: (a) retention conditions (immediate, 7 sec rest, and 7 sec filled with a mental classification task), (b) movement lengths, and (c) types of criterion movement (active, active plus resistance, passive). The code condition was a between-S variable and 24 Ss were assigned to each group. All other conditions were within-S variables. Although Ss appeared less consistent in using EL relative to D+L code (significant greater VE for EL information but no differences in terms of CE), both codes showed the same retention characteristics. That was, little loss of accuracy over the 7 sec retention interval unless it was filled with the interpolated task. Furthermore the other two factors (movement length and types of criterion movements) produced exactly the same effects on the retention

characteristics of both codes.

It is now well accepted that to separate D from EL cues in a reproduction accuracy task, experimenters have to vary the starting position of the criterion and recall movements. By systematically varying different combinations of starting positions, Stelmach and Kelso (1973) tested whether such combinations had any differential effects on the retention of D and EL information over a 10 sec, unfilled, retention interval. They found that both D and EL cues are affected to some degree by combinations of starting positions although EL appeared less affected (i.e. more stable) than D. These findings were interpreted by the authors to indicate that caution should be exercised when interpreting data that attempt to separate D and EL cues by altering combinations of starting positions.

Hagman and Francis (1975) investigated the effects of knowing in advance (i.e. before executing the to-be-remembered movement) the cue upon which immediate movement reproduction would be based. They compared six conditions in a six independent group design with 30 Ss in each group. The conditions came from a factorial combination of three pre-movement instruction or cue to be learned (D, EL, and D+L) and two types of recall (D, or EL). They found equivalent immediate recall of D and EL information when pre-movement instruction contained the cue to be recalled (i.e. D instruction/D recall = EL instruction/EL recall = D+L instruction/D+L recall). However when the cue recalled was not announced in the pre-movement instruction (i.e. D instruction/EL recall and vice versa) then detrimental effects were observed. In effect D cuing instruction produced significant superior recall of D information relative to EL, whereas under EL cuing

instruction EL recall was significantly superior relative to D. They concluded that reproduction was code-specific, that is to say, was correctly reproduced what was correctly coded due to directed instruction.

Diewert (1975) independently manipulated D and EL cues in two successive experiments. In the first experiment D reproduction was compared under four retention conditions: (a) immediate reproduction (IR), (b) reproduction after 30 sec mental rehearsal (MR), (c) after 30 sec motor interfering activity (MI), and (d) after 30 sec visual interfering activity (VI). The only dependent measure to show significant results was VE from which he found that D was retained over an unfilled interval (IR ≃ MR) and that MI had stronger interfering effects than VI. In the second experiment, EL reproduction was compared under the same retention conditions. In this case, he also found EL information stable over time (IR ≃ MR) but equally and highly affected by both MI and VI. Diewert concluded that both D and EL information were codable since no forgetting occured over unfilled interval. However he also concluded that D information was coded in a kinesthetic code since VI did not have any appreciable consequences while EL information was coded in an integrated V-K code since both VI and MI had strong interfering effects. An overall post hoc comparison between D scores and EL scores revealed a significant superiority of EL reproduction over D reproduction. This finding would suggest, according to Diewert (1975), that the resulting V-K code for EL information was the mechanism behind the relative superiority of this cue.

Taken collectively the studies which have examined D and EL cues have found that those cues do have different encoding and retention

characteristics when the to-be-reproduced movements are E-defined. Immediate reproduction of EL information has been found significantly superior to immediate reproduction of D information (Marteniuk & Roy, 1972; Marteniuk et al, 1972). A non-significant superiority of EL over D information has also been reported by Posner (1967b), Laabs (1973), as well as by Hagman and Francis (1975).

Furthermore EL information has been found to be rehearsable, i.e. not forgotten over an unfilled retention interval (Keele & Ells, 1972; Laabs, 1973, 1974; Diewert, 1975) while D information has been found to be not rehearsable, i.e. spontaneously decayed over an unfilled retention interval (Posner, 1967b; Laabs, 1973, 1974). On the latter, Diewert (1975) has provided contradictory evidence according which D would also be rehearsable. Concerning the effect of a retention interval filled with an attention-demanding task, EL information reproduction has been found to be significantly diminished (Keele & Ells, 1972; Laabs, 1973) while D information has been observed to be unaffected by a mental interpolated task (Posner & Konick, 1966; Posner, 1967b; Laabs, 1973) but affected by a motor interpolated task (Laabs, 1974; Diewert, 1975). Concerning the last point, it is worth mentioning again that Diewert (1975) has found EL information to be equally diminished by a visual and a motor interpolated task while D information was diminished only by a motor interpolated task.

Concerning the distinction between EL and D+L information, the former has yielded significant greater VE than the latter but both displayed same CE scores. In addition D+L manifested the same retention characteristics than EL information (Keele & Ells, 1972)

suggesting that both cues have the same encoding and retention characteristics (Hagman & Francis, 1975).

In summary, when criterion movements are E-defined, the conclusions of Marteniuk and Roy (1972), Keele and Ells (1972), Laabs (1973, 1974), Stelmach and Kelso (1973), and Diewert (1975) are that encoding of EL information is more precise than D information and that both cues do have different retention characteristics.

S-defined movement. Marteniuk (1973) compared the coding characteristics of D and EL information over three retention conditions: (a) immediate reproduction, (b) reproduction after a 10 sec unfilled retention interval, and (c) reproduction after a 10 sec retention interval filled with a mental interpolated task. He found that both cues had access to the central processing capacity in that forgetting did not occur until rehearsal was blocked by the introduction of the interpolated task. Furthermore, such finding was found to be true also for both active and passive movement. However he concluded that EL and D were centrally represented in different degrees of exactness from the observation of a significant movement cue main effect: reproduction was better when based on EL than on D information.

The fact that D information was also well retained unless an interpolated task was introduced in the retention interval was in contradiction with Laabs' results (1973) which led him (Laabs, 1975) to suggest that failure of Marteniuk (1973) to find any difference between D and EL was probably due to a lack of statistical power in Marteniuk's study (1973). Arguments by Marteniuk (1975b), as well as research by others (Jones, 1974; Roy, 1976) make it clear that the discrepancy can now be explained by the types of movement used:

S-defined movement in one case (Marteniuk, 1973) and E-defined movement in the other (Laabs, 1973).

Jones (1974) directly compared E- and S-defined movements in a series of three experiments. Results of the first experiment indicated that concerning S-defined movements, retention of D+L information was stable over time (15 sec rest) but disrupted by an attention-demanding task inserted during the 15 sec retention interval. Concerning E-defined movements, D+L information spontaneously decayed over the unfilled retention interval. More importantly results of Experiment II evidenced exactly the same pattern of forgetting for D relative to EL information in the case of S-defined movement: stable performance over an unfilled retention interval and decreased performance over a filled retention interval. Finally, Experiment III showed that augmented peripheral feedback had little effect on the accuracy of D reproduction. Jones concluded that voluntary movements (S-defined) were rehearsed during unfilled retention intervals and this was true for both D and EL information. On the contrary, constrained movements (E-defined) were not rehearsed and were subject to spontaneous decay. That finding was also true for both D and EL information.

Three experiments were conducted by Stelmach, Kelso and Wallace (1975) in order to examine Jones' hypothesis (1974) that accurate recall of S-defined movements was mediated by S's ability to preset effector mechanism and monitor their efferent output. The first experiment involved the comparison between the reproduction of EL and D information for S-defined movements after a 15 sec unfilled retention

interval. The results revealed that preselected EL was superior to preselected D information which was at variance with Jones' results (1974). Stelmach et al (1975) concluded that the efference copy attached to D information was not essential for the accurate reproduction of such information.

The conclusion by Stelmach et al (1975) was supported in an experiment realized by Roy and Diewert (1975) in which they directly compared D and EL information for both S- and E-defined movements. The task involved moving a slide along a linear track a distance of one-half the total distance of the track. That distance (the standard) was then immediately reproduced. During the presentation of the standard, reaction time to an auditory probe was recorded. One group of Ss determined their own standard (S-defined) while the other group moved the slide to a stop located at the standard distance (E-defined). All Ss were told that the standard was one-half the total distance. Probe reaction time was not found to be different for the two groups as well as reproduction accuracy as measured by AE. The authors were led to conclude that the important variable in determining the codability of D information was not whether E or S defined the standard but the availability of a strategy based on prior knowledge of when to stop moving. Since both groups had that prior knowledge no differences was found between D and EL information.

Roy (1976) directly tested whether preselection (i.e. prior knowledge about the to-be-reproduced distance) or efference (i.e. S is able to terminate himself an S-defined movement) was the important variable in the codability of D information. In Experiment I he compared three reproduction conditions: (a) S-defined plus prior knowledge,

(b) E-defined plus prior knowledge, and (c) E-defined without prior knowledge. He found that E-defined movement without prior knowledge (i.e. totally E-defined) exhibited significantly greater errors than either of the other two conditions. Furthermore there was no difference between the two conditions with prior knowledge. That was interpreted as meaning that the important variable was prior knowledge and not efference (i.e. active termination of a movement). Such conclusion was further supported in another experiment (Roy, 1976, Experiment III).

As a summary for all those studies carried out on cue effects in movement reproduction it can be concluded that D and EL cues have different encoding and retention characteristics when the to-be-reproduced movements are E-defined. However when the to-be-reproduced movements are S-defined, the movement cues seem to have different encoding characteristics (Marteniuk, 1973; Stelmach _et al_, 1975) although they appear to have identical retention characteristics (Marteniuk, 1973; Jones, 1974). There is no forgetting during an unfilled retention interval and, in contrast, forgetting during a filled retention interval. However recent evidence (Stelmach _et al_, 1975; Roy & Diewert, 1975; Roy, 1976) seem to suggest that whether or not D information will spontaneously decay over unfilled retention interval is not dependent upon S's ability to terminate himself a movement (as in S-defined movement) but upon prior knowledge about the location at which the to-be-reproduced movement will be stopped. When Ss have prior knowledge, D information does not decay over unfilled retention conditions. On the other hand EL information regardless of prior knowledge is not forgotten over unfilled retention conditions. Taken collectively those results would support the view that EL information is more easily codable or encoded in a more precise format than

D information. Unfortunately no studies are available in which the encoding and retention characteristics of the starting location of movements have been investigated.

Studies on motor recognition

As mentioned previously, no studies have been published concerning movement recognition by means of recognition latencies. However a few studies have been conducted on motor recognition using different dependent variables (e.g. percentage of recognition errors) and those studies will be reviewed here.

Marshall (1972) ran parallel motor recognition (Experiment I) and motor recall experiments (Experiment II) in order to determine if recognition and recall measures of motor memory were the same functions for the same variables. The common variables were amount of reinforcement of the criterion movement (one or six repetitions) and duration of an unfilled retention interval (5, 60 or 90 sec). The measure for recall was the degree of accuracy in the reproduction of the criterion movement (both AE scores and CE scores). For recognition, the measure was the proportion of responses correct in a choice situation following learning of the criterion movement where the discriminability of alternatives in the choice test was also a variable. Since the starting locations were the same in the criterion and test movements, both distance and end-location information were reliable cues in movement recognition and recall. Marshall (1972) found that both recognition and recall were significantly affected by the same variables: (a) performance increased as a function of reinforcement, and (b) decreased as a function of the lengths of the retention intervals.

Kantowitz (1974) compared recognition performance of distance information under three retention conditions: (a) 0 sec delay, (b) 20 sec unfilled, and (c) 20 sec filled with a tapping task. He found a significant increase in recognition errors after an unfilled retention interval with no further increase due to the interpolated, attention-demanding task. Such results were consonant with what has been found for the recall of distance information (Posner, 1967b; Laabs, 1973).

Although Marshall (1972) and Kantowitz (1974) found both recognition and recall to be affected by common variables, Newell and Chew (1974), found recognition and recall to be differently affected by feedback withdrawal. They used a motor timing task in which S had to learn to move a lever over a distance of 24.03 cm in exactly 150 msec. Ss were given 70 learning trials with knowledge of results followed by 40 trials in which knowledge of results was withdrawn by eliminating visual and/or auditory feedback and also by eliminating verbal knowledge of results from E in terms of actual movement time taken by S. The actual movement time taken by S was interpreted as the index of recall while the difference between S's estimate of his movement time and his objective movement-time score was interpreted as the index of recognition. It must be acknowledged that this way of interpreting recall and recognition is quite different than from the usual learning/test-trial paradigm for recognition and recall. Nevertheless, Newell and Chew (1974) found that feedback withdrawal produced a decrement in response recognition but not recall during the initial phase of knowledge of results withdrawal. Results were interpreted by the authors as

meaning that motor recognition and motor recall were reflecting different underlying mechanisms; perhaps a response selection and initiation mechanism in recall and a feedback-based comparison mechanism in recognition, the latter being found affected in their experiment.

The same procedure of indexing recall and recognition was used in another experiment by Newell (1975). In that experiment the task was to learn to project a ball a criterion distance. Again, visual flight feedback was found to be a determiner of motor response recognition with no effect on response recall. Few other experiments (Schmidt & White, 1972; Newell, 1976) have been reported in which performance verbal estimate from S was used as a mean of measuring the accuracy of the response recognition mechanism.

An experiment by Newell and Boucher (1974) was conducted in order to test the hypothesis that motor response recognition involves two independent processes: (a) evaluating response-produced feedback stimuli, and (b) associating a label from an interval scale to the stimuli. Ss practiced a linear positioning movement to a physical stop before verbally estimating the movement distance either in inches or in mm and reproducing the movement in a single criterion/test trial. Results were interpreted by the authors as supporting the hypothesis.

Finally, it should also be mentioned that effort to analyze storage and retrieval processes in motor memory has been realized by means of a serial reaction time task (Schutz, 1972; Goodman & Schutz, 1975). By experimentally manipulating temporal spacing of the stimuli, their sequential probabilities, repetitions, and the like, one can have an insight to the organization of the motor responses in memory.

Schutz (1972) has developed a model to account for results on this type of task. Unfortunately validation and generalization of the model awaits further experimentation (Goodman & Schutz, 1975, p. 146).

In summary, recognition and recall are sometimes similarly, and at some other times, differently affected by common variables. This would be consistent with conclusions reached by Kintch (1970) concerning verbal memory when he said that: "a large number of experimental variables affect recognition and recall in much the same way. This is true, for instance, for the important class of temporal variables... such as lag between presentation and test, and massing and spacing of repeated presentations" (p. 334). Concerning movement information, Marshall (1972) and Kantowitz (1974) have in fact shown that recognition and recall were similarly affected by temporal variables.

On the other hand, Kintch (1970) added that other variables have differential effects on the recognition and recall of verbal information, for instance, "less frequent words are more easily recognized but the more frequent words are best recalled; intention to learn improves recall considerably, but is irrelevant for recognition" (p. 236). In a similar manner concerning motor memory, Newell and his collaborators have shown that feedback was much more important for recognition than for recall of movement information.

However, still very few studies have been conducted up to now on motor recognition memory and no conclusive statements can be reached at the present time concerning the recognition processes in motor memory. Thus the need for the present series of experiments.

<u>A complementary approach: recognition memory latencies</u>

Over the past decade a complementary approach to memory recall has been developed which is now known as "speeded memory-recognition paradigm" although the paradigm has been more appropriately called a "character classification task" by Nickerson (1973). Here, the method is to present a list of items for memorization. S is then asked a question about the memorized list; he answers as quickly as he can, and his delay in responding is measured.

The stimulus ensemble consists of all potential test stimuli. From among these, a set of <u>n</u> elements is selected arbitrarily and defined as the memory set or positive set. These items are presented as a list for the S to memorize. The remaining items are called distractor set or negative set. When a test stimulus is presented, the S must decide whether it is a member of the positive set. If it is, he makes a positive response, for example, by saying "yes" or by pressing one of two buttons. If not, he makes a negative response, for example, by saying "no" or by pressing the other button. The measured RT (sometimes referred to as response latency) is the time from test-stimulus onset to response.

The aim is generally to produce error-free performance such that the responses are almost always correct. However by applying time pressure the experimenter can induce some of the memory mechanisms at work to reveal themselves, not by how they fail, but by how much time they need in order to succeed (Sternberg, 1975). Therefore in most experiments, conditions and payoffs are arranged such that the error rate of any S is below 10%, and usually around 2%. RT measures from only correct positive and negative responses are analyzed. On the

other hand, Ratcliff and Murdock (1976) have shown that correct RT measures can also be fruitfully analyzed in experiments in which error rates are much higher, for example around 25%.

The speeded recognition paradigm is based on the principle that the latency of the response either positive or negative, is considered to reflect a series of "mental events" or stages. Those stages would lead from the identification of the test stimulus to the execution of the response. Sternberg (1966, 1967a, 1969a, 1969b) proposed what he called "the additive factor method" which could be used to help establishing the existence and properties of stages, as well as the relations between them. In this manner the experimenter must look at the factor/stage relations in a multi-factor experiment. The general idea is that when factors influence no stage in common, their effects on mean RT will be independent and additive because stage durations are additive. On the other hand when two factors influence at least one stage in common, then their effects on RT will probably not be additive and the most likely relation will be some sort of interaction.

A stage here is meant to imply a series of successive processes that operate on an input to produce an output and contribute an additive component to the RT. Additivity is defined in terms of independence of different mean stage-durations and is tested by appropriate constrasts or by testing the interaction term in an analysis of variance (Sternberg, 1969a).

In one of the first series of experiments reported, Sternberg (1966) used the ten digits (i.e. 0 to 9) as the stimulus ensemble from which he randomly chosen some of them to form memory sets of from

one up to six different digits. Memory set size varied at random from trial to trial (procedure known as the "varied set procedure"). To-be-memorized digits were visually displayed singly in front of S, at a fixed locus for 1.2 seconds each. There followed a 2.0 sec delay, a warning signal, and then the test digit. For every value of memory set size, positive and negative responses were required with equal frequency. Eight Ss received each 24 practice trials and 144 test trials. Sternberg found response latencies to be a linear increasing function of memory set size with linear regression accounting for 99.4% of the variance of the overall mean response latencies. Furthermore there were no differences between positive and negative responses.

In a second experiment, Sternberg (1966, experiment II) used a "fixed set procedure" in which the same elements of a given memory set were used over successive trials. Each S worked with nonintersecting positive set size of either 1, 2, or 4 digits, whose composition was varied from S to S. In this experiment stimulus probability was held constant as compared with covariation of memory set size and stimulus probability in the varied set procedure (Experiment I). Again, response latencies were found to be linearly related to memory set size with no difference between positive and negative responses. From both experiments, Sternberg concluded that the linearity of the latency functions suggests that the time between test stimulus and response is occupied in part by a serial comparison (scanning) process. An internal representation of the test stimulus would be compared successively to the symbols in memory, each comparison

resulting in either a match or a mismatch. The time from the beginning of one comparison to the beginning of the next (the comparison time) has the same value for successive comparisons and was estimated to be 37.9 ± 3.8 msec (the slope of the regression equation) per memory item, representing an average of between 25 and 30 symbols per second. Furthermore the equality of the slopes of the positive and negative responses was interpreted as meaning that the scanning process was exhaustive: even when a match has occured, scanning continues through the entire series. Sternberg reasoned that if positive responses were initiated as soon as a match occured (as in a self-terminating search), the mean number of comparisons on positive trials would be $(\underline{n}+1)/2$ rather than $\underline{n}$. In a self-terminating search the latency function for positive responses would thus be half the slope of the function for negative responses. Since the slopes were equal, search would be exhaustive. Sternberg was therefore led to conclude to the presence of a high-speed, serial, exhaustive scanning process of memory in which a test item is compared successively to the items in memory at an average rate between 25 and 30 items/sec.

In another experiment Sternberg (1967b) tried to determine the difference between RT to intact and degraded test stimuli for memory (M) sets of size M = 1, 2, and 4. The stimulus ensemble was again the ten digits and degradation of the test stimuli was made by superimposition of a check board pattern. He replicated the findings that response latencies increase linearly as a function of memory set size with no differences between the two types of responses (positive and negative). This was reflected in the slope "β" of the regression equation relating response latencies and memory set sizes

[$RT = \alpha + \beta(M)$]. On the other hand, degradation affected mainly the "α" intercept of the regression equations with little effects on the slope "β", espacially in the second session of testing. Finally, test-stimulus degradation had no differential effects on latencies of positive and negative responses. Sternberg thus interpreted the two parameters of the reaction-time function in the following manner. The slope, "β", of the function is a measure of the mean time taken by the comparison of the test-stimulus representation to the memory representation of one character (comparison time). The zero intercept, "α", is a measure of the time taken by events before and/or after the series of comparisons. These include the formation of a stimulus representation which was in fact affected by degradation in his experiment.

Sternberg (1967a) also tested the effects of naming the memory item that followed the test item in the list. Such procedure implied that S had to localize at the same time, the item's serial position in the memorized list. Five different memory set sizes were used ($M = 3$, 4, 5, 6, and 7) and stimuli were again digits. Positive RT were found to be linearly related to memory set size. However for lists of all lengths there was a marked primacy effect: RT increased with serial position of the test item. Sternberg concluded that the scanning process used to determines the presence of an item in a list is exhaustive, whereas having to localize a particular item in the memorized list implies a much slower self-terminating process whose average rate is about four items/sec.

In reviewing four of his experiments (three of them mentioned above) in which digits were used as memory and distractor items,

Sternberg (1969a) was led to suggest the presence of four stages comprising the total RT. Those were:

1. Encoding stage (or pre-processing stage) during which there is a transformation of the test stimulus into some representation of it or its identity. This stage would be primarily affected by the quality, detectability, and intensity of the stimulus presentation.

2. Comparison stage during which the test stimulus is compared alternatively against each member of the memorized set. This search process is said to be serial and exhaustive so that this stage is mainly affected by the number of elements in the memory set.

3. Binary-decision stage representing the decision reached at the end of the comparison stage (i.e. "yes" the test stimulus was part of the memory set or "no" it was not).

4. Translation and response organization stage at which time the selected response is translated into a motor pattern and emitted. This stage would be mainly affected by the proportion of positive/negative responses, and by the stimulus-response compatibility.

An experiment was designed by Sternberg (1969a, experiment V) in order to test the additivity of stage duration (or absence of interaction effects among factors) in a multi-factor experimental design. Three factors were examined, each at two levels. The stimuli were numerals and the responses were spoken digits. The first factor was number of equally-likely stimulus-response alternatives (2, or 8). The second factor was stimulus quality (intact, or degraded) and the third one was S-R compatibility (compatible, or incompatible). He found no interaction between stimulus quality and S-R compatibility and perfect additivity with each other (absence of a three-factor

interaction). However both factors were in interaction with the third factor, the number of alternatives. Sternberg interpreted those results as meaning that: (a) stimulus quality was in fact affecting only the stimulus encoding stage, (b) S-R compatibility affected only the translation and response organization stage, (c) number of alternative affected both previously mentioned stages. Taken collectively, those results were interpreted as supporting the model of stages previously presented.

As mentioned previously, early experiments by Sternberg have been carried out using digits as stimulus material with memory load not exceeding the memory span (i.e. a maximum of M = 7). However, since then a large number of studies have shown the phenomenon (linear RT functions, and with approximately equal slopes for positive and negative responses) to be reliable. This phenomenon has been demonstrated in experiments using positive sets up to 10 letters (Wingfield & Branca, 1970), and up to 12 common words (Naus, 1974). It has also been demonstrated with stimuli such as drawings of familiar objects (Hoving, Morin, & Konick, 1970), shapes (Swanson, Johnsen, & Briggs, 1972), auditorily-presented phonemes (Foss & Dowell, 1971), as well as words of various lengths (Clifton & Tash, 1973). In addition, the phenomenon has been found little affected over different speed/accuracy instructional sets (Swanson & Briggs, 1969), ages (Howing _et al_, 1970), and prolonged practice (Kristofferson, 1972; Lively, 1972).

In summary, the main feature of Sternberg's theory is that speeded recognition of a test item would include a scanning process (comparison stage or Stage 2) that would be serial, and exhaustive. It would be

serial because mean RT increase as a linear function of memory set size. Secondly, it would be exhaustive because the slopes of the RT functions are equal for positive and negative responses, otherwise the slope of the negative responses would be twice that of the positive responses (Sternberg, 1967b, p. 46).

However Sternberg (1975) mentioned that some procedures consistently produce nonlinear set size functions: when members of positive sets are distinguished from members of negative sets by physical features, by large differences in familiarity or by frequency of presentation. One possible explanation according to Sternberg (1975), would be that such procedures would provide an alternative basis for the positive-negative decision that S may find to be more efficient than the scanning process. Later that alternative basis will be discussed when Atkinson and Juola's model (1974) based upon both familiarity and search will be presented.

Three predictions of the serial exhaustive scanning model would be that (a) RT for positive responses should not be affected by the serial position of the test item in the memory set since the scan continues at a constant rate for all memory items, (b) for the same reason, the probability with which a member of the memory set is presented as a test item should not affect RT for positive responses, and (c) repetition of a memory item in the same memorized list should not affect its RT response. However from experiments having used varied-set procedures, evidence is accumulating that shows none of the above-mentioned predictions are empirically supported.

For example, Burrows and Okada (1971) used the speeded memory-recognition paradigm with digits as stimulus material with memory

set sizes of M = 1, 2, 3, and 4. They replicated earlier findings of identical, increasing linear functions for both positive and negative responses. However when testing for serial position effects they found marked primacy and recency effects in RT for positive responses. Such primacy and recency effects have also been obtained by Corballis, Kirby and Miller (1972). Other investigators have either found pronounced primacy effects (Klatzky, Juola & Atkinson, 1971) or pronounced recency effects (Forrin & Morin, 1969).

Concerning the second prediction, Theios and collaborator (Theios, 1973; Theios & Walter, 1974) have convincingly demonstrated that positive responses to high-probability test stimulus are faster than positives responses to low-probability test stimulus. Finally, with regard to repetition effects, Baddeley and Ecob (1973) have shown that positive responses to repeated items in a memory set are significantly faster than to non-repeated items.

Evidence in contradiction with predictions from the serial-exhaustive model have led some authors to suggest complete rejection of that model. For example Corballis and Miller (1973) have proposed a model based on the trace strength of the memory items in which the decision would be accomplished by direct access to the internal representation of the test stimulus. The linear relationship between RT and memory load would reflect a decision process rather than a memory (or retrieval) process. There would be a scan of each trace strength representing each memory item and a decision would be reached after a discrimination between each memory trace with that of the test stimulus. Theios (1973) has proposed a "serial self-terminating, memory stack model" in which for example high-probability memory

item would be search first, explaining recency and primacy effects.

Recently, Sternberg (1975) acknowledged that his serial exhaustive model cannot account for the empirical evidence that come in contradiction with the model and also demonstrated that a pure trace-strength model could not either. He argued that a combination of both models as suggested by Atkinson and Juola (1974) could be a fruitful entreprise (see also: Reed, 1976).

In fact, Atkinson and Juola (1974) (Atkinson, Herrmann & Westcourt 1974; Juola, Taylor & Young, 1974) have proposed a model based on a dual process of trace-strength (or familiarity) of the test-item, and of a serial retrieval process of the memory item. Because of its significance for movement related information, the model will be presented in the following section of this chapter.

As stated in the introduction of this dissertation, the purpose of this series of experiments is not to test different models of memory recognition. Too many procedural problems have yet to be resolved in applying speeded memory recognition paradigm to movement related information before predictions from different models can be made. Recently, Ratcliff and Murdock (1976) have revisited four classes of models including Atkinson and Juola's model using a different method of analyzing RT data, namely latency distributions as opposed to the more traditional measure of mean latency. They concluded that none of them was actually entirely satisfying nor unsatisfying. One model is able to explain results that another model cannot and vice versa. In addition, Taylor (1976) has shown that it is very difficult to contrast different models at the present time because identical predictions can sometimes be made from different models.

In summary, the current literature shows that the speeded recognition paradigm produce reliable outcomes although their interpretations must be, at the present time, very careful and cautious. Before leaving this section on recognition memory latencies, four different aspects of the paradigm will be reviewed: (a) retention interval effects, (b) translation or recoding effects, (c) main effect of positive and negative responses, and (d) controversies about this paradigm.

Retention interval effects. In a sense, effects from different retention intervals should act in a way similar to that of memory set sizes. The larger the size the longer RT and the longer the delay before the presentation of the test stimulus, the longer the RT. Of course, if RT is linearly related to memory set sizes, as mentioned before, RT will probably not be linearly related to length of the test delay. RT may simply be longer for longer delays. As a matter of fact, Waugh (1970) and Peters (1974) have shown that the comparison process is slower when it takes place in long-term memory (i.e. after a very long delay between items presentation and test stimulus) relative to short-term memory.

Clifton and Birenbaum (1970) directly tested three short delays of the test stimulus, .8, 2.8, and 4.8 sec. They used digits as stimulus material with seven different memory set sizes of from 1 up to 7 digits. Results were that: (a) the main effect of delay was nonsignificant for both positive or negative responses, and (b) the memory set size x delay interaction was nonsignificant. One obvious interpretation of the absence of interaction (Sternberg, 1969a; Taylor, 1976) would be that given the known effect of memory set size

on the comparison stage, then the retention intervals do not affect that stage. However one variable also manipulated by Clifton and Birenbaum (1970) was the number of elements in the memory sets that preceeded and followed the test stimulus. Thus they were able to look at the serial position effects. In fact they found pronounced recency effects but at the .8 sec delay only. Those results as well as other results allowed the authors to say that at very short delays such as .8 sec a different scanning strategy was used by the Ss. That point of view is not incompatible with Atkinson and Juola's model (1974).

Translation effects. A phenomenon arises when the test stimulus is in a format different than that of the memory items. Suppose for example that all memory items are digits. The test item is a letter, and S must respond based upon a previously learned associational scheme, whether the letter correspond to a previously associated digit or not. When the memory item and the test item do not match because both have encoded according to different dimensions or different modalities, and that one of them must be translated or recoded before comparison can take place, then the memory item will be recoded into the format of the test item and not the opposite, prior to the comparison process (Swanson, Johnsen & Briggs, 1972). The recoding effect would thus be localized at Stage 2 of Sternberg's model (Swanson et al, 1972; Cruse & Clifton, 1973). However Clifton, Cruse & Gutschera (1973) have shown that this will happen only when the presentation rate of the memory items is so rapid (e.g. one item every .4 sec) that S do not have time to recode each memory item into the format of the test item. When time permits (e.g. a presentation rate of one item every 1.6 sec), then each memory item

is immediately translated upon its presentation into the format of the test item and no effects are found during the comparison stage. As suggested by Sternberg (1975, p. 28), the translation effects tell us something about the coding of information of the memorized set.

Positive versus negative responses. Sternberg (1966, Experiment I and II) found no difference between positive and negative responses. Based upon statistical analyses on slopes as well as on the intercepts between RT functions of both positive and negative responses, Sternberg concluded to the equivalence between the two types responses across memory set sizes of from 2 to 6 elements. The same conclusion has also been reached by Anders, Fozard, and Lillyquist (1972), Dardley, Klatsky and Atkinson (1972) and Lively (1973). In those experiments a varied-set procedure was used. However Sternberg (1966) noted that for memory set size of $M = 1$ in this varied-set procedure, positive responses were significantly faster (by 50 msec ± 20.1 msec) than negative responses. The fact that $M = 1$ produces atypically fast positive responses has also been noted by Clifton and Birenbaum (1970) and Baddeley and Ecob (1973). That would confirm what is known from the fast, "same/different" judgment paradigm. Response when a test stimulus is the same as only one stored memory item is significantly faster than a response when a test stimulus does not match (or is different than) a stored memory item (Posner & Mitchell, 1967; Nickerson, 1973). Furthermore, using fixed set procedures, several studies have indicated a significant main effect of response types. Faster positive responses (by about 50 msec) are gained across different memory set sizes (i.e. no response x memory set

interaction). Such results have been reported by Briggs and Blaha (1969), Sternberg (1969a, Experiment IV, p. 291), and Miller and Pachella (1973).

Controversies about this paradigm. The first, basic controversy is relative to whether or not there would be any process such as search or retrieval in recognition memory. A commonly adopted point of view (Bower, 1967; Kintsch, 1970) is that recall memory involves two different processes, namely storage and retrieval; whereas recognition involves only a storage process. In this view, recognition is seen as a decision process based upon an evaluation of the familiarity or response strength of the test stimulus. There would be no process such as search or retrieval because the test stimulus would have direct access to its stored memory representation (Corcoran, 1971). As mentioned previously, some authors (e.g. Sternberg, 1969a; Theios, 1973; Atkinson & Juola, 1974; Ratcliff & Murdock, 1976) have demonstrated that there would have a retrieval process even in recognition memory. Reviewing the evidence on this matter, McCormack (1972, p. 21) stated that "because of the failure on the part of the numerous investigators to define what they mean by retrieval, and also because of the lack of any adequate theory of the retrieval process, data are not conclusive with respect to the issue under discussion". However he added that if retrieval is defined as being synonymous with a search process of some minimal degree of complexity, then it must be concluded that "recognition may be primarily characterized by a storage process" (p. 35). This would mean that in recognition, the search process when it operates is much less complex than in recall. For example, when retrieval is in

operation in recognition it may involve a single loop search whereas it involves complex series of search loops in recall (McCormack, 1972, p. 35). Based upon the evidence reviewed above, the position taken here is that there would be a minimal retrieval process in recognition, though perhaps less complex than in recall.

The second controversy about this paradigm is relative to the assumptions at the base of the "additive-factors method" proposed by Sternberg. It must be mentioned at this point that five properties are assigned to the stages by Sternberg (1969a, p. 282): (a) mean RT scores reflect a series of a finite number of stages of theoretical significance, (b) the execution of stages is serial such that each stage starts its operations when the preceeding stage has finished, (c) the mean time duration of one stage is independent of the mean duration of other stages, (d) a stage should be able to process no more than one signal at a time, and (e) stage durations would be stochastically independent, namely the time required by the various stages on a given observation or trial should be independent of one another. Those properties were interpreted as assumptions to Sternberg's paradigm. However, Taylor (1976) has shown that in fact only two fundamental assumptions are needed: (a) the mean total RT reflects a fixed and finite set of stages, and (b) stages when not independent are linearly dependent. Corrections can thus be made to the basic stage times required by independence or temporal overlap among the stages, those corrections being expressible as linear functions of the stage time involved. Therefore the most controversial properties of stage independence and nonoverlaping stage durations are not necessary, provided one assume the dependence to be predictable (e.g. linear

dependence as demonstrated by Taylor).

Another controversy has to do with the capability of making accurate measurements of the different stage times. For example, a series of studies by Briggs and his collaborators (Briggs & Blaha, 1969; Swanson & Briggs, 1969; Briggs & Swanson, 1970) was undertaken in order to estimate the mean duration and processing rate of the various stages identified by Sternberg. They started from the observed linear RT function already mentioned, which is expressed as $RT = \alpha + \beta(M)$ where mean RT is a linear function of memory set size. They found that the intercept "α" could be decomposed into at least two sub-stages: (a) initial encoding plus response decoding time on the one hand, and (b) an estimate of Sperling's scan (1967) function or input sampling time on the other hand. Furthermore the constant slope "β" could also be separated into two components, one of which was identified with the time required for the test stimulus to retrieve the memory representations of the positive set. The other component was interpreted as time per test to compare each memory-set items with the test stimulus. Authors were providing mean sub-stage durations for each of the components. However Taylor (1976) argued that given the methods currently available, it is in fact hazardeous to speculate from measurements of the different stage times. Such accurate measurements could only be achieved through a long series of multi-factor experiments in which the assignment of factor to a stage or stages has been validated.

Encoding and recognizing movement information

Several studies have been conducted up to now with the purpose of investigating encoding processes in movement reproduction. It is

interesting to note that those studies went into several different directions without an integrating unifying theory of encoding processes in motor memory. A number of investigators thought of encoding as differentiating between recall based upon location and distance information (e.g. Laabs, 1973). A few investigated the role of vision in the encoding of kinesthetic information (Diewert, 1975); while others looked at the role of verbal encoding of kinesthetic information (Shea, 1974; Colby, 1974). Finally, conceptual categories of movement information was investigated by Nacson, Jacger & Gentile, 1972; and Gentile, 1974.

There are several ways in which different "levels" of encoding can be divided and one way is the division between primary and secondary codes (Galanter, 1967, p. 98; Bower, 1967). For example, Bower (1967) proposed that the representation stored is either the primary code by which an event is recognized, a secondary code that labels the primary code, or both. He further proposed that in a primary code, the stimulus is represented in coded form as an ordered list of attributes with their corresponding values. In the case of the secondary code, only a verbal label is stored (either auditory, phonetic, articulatory or linguistic). Posner, Boies, Eichelman, and Taylor (1972) made a similar distinction between a physical and a name code whereas Peters (1974) used a distinction between a physical and an associational code.

Atkinson and his collaborators (Atkinson & Juola, 1974; Juola et al, 1974; Atkinson et al, 1974) have presented a model of levels of encoding with the particular purpose of explaining and predicting

results obtained in a recognition-memory paradigm. Considering that purpose and considering that Atkinson's model bears important implications for a theory of the encoding processes in motor memory, that model will be presented and adopted here.

Basically two formats can assume the representation of the external information within the memory system. The first one is a perceptual code which would be a unitary representation of the stimulus, specified in terms of a set of features within the particular modality. External information can also be encoded at a second level of complexity or in a second type of format called a conceptual code. The verbal label "5 cm", the kinesthetic (perceptual) code associated with moving a distance of 5 cm, the visual (perceptual) code associated with seeing a line of 5 cm long, and perhaps also the efference copy associated with the command of moving for a distance of 5 cm, could all be mapped onto the same conceptual code. According to Atkinson et al. (1974), conceptual codes each with their associated perceptual codes available to the memory system would be permanently stored and organized within a functional partition of the long-term store that is referred to as the conceptual store. Furthermore, perceptual and conceptual codes would form the basic elements of memory structures stored within a second partition of the long-term store that might be called in the case of movement information, the event or episodic store. Information within episodic store is stored together with spatial and temporal features of each element (i.e. each movement of a longer sequence) forming the episode. A block diagram illustrating the relationships between perceptual and conceptual codes is illustrated in Figure 1. What are the implications for motor memory?

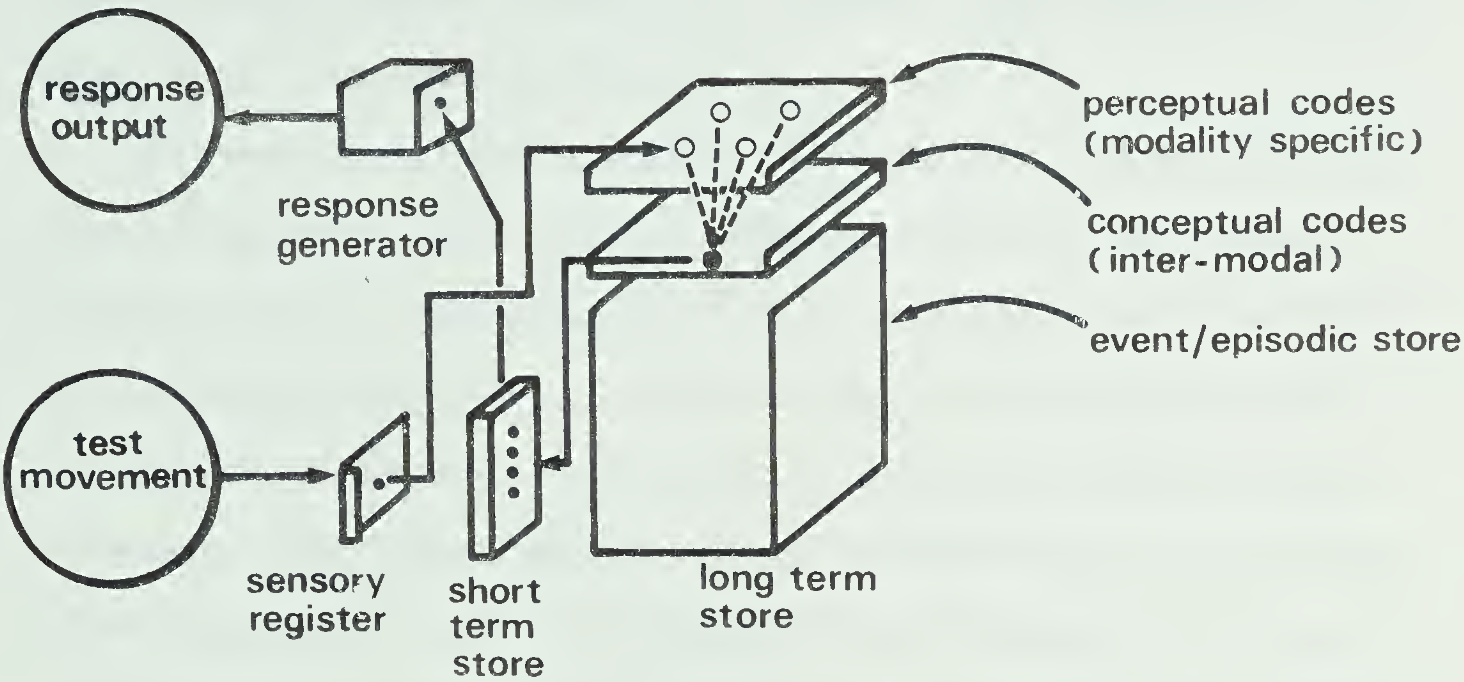

Figure 1. A block diagram illustrating the relationships between perceptual and conceptual codes in a memory-search task that would involved search of a movement through a sequence of movements stored in short term store. Here, the kinesthetic (perceptual) code is activated by a given test movement but other entries from other modalities would also be available for the same conceptual code (adapted from Atkinson, Herrmann & Westcourt, 1974).

The first implication is that the kinesthetic (perceptual) code might represent a great deal of what is already known about encoding movement information in the kinesthetic modality (e.g. Posner's definition of a kinesthetic code as well as the already mentioned superiority of location over distance information). However, other properties of the code are still not well understood.

A second implication is related to the idea of a conceptual code and of a conceptual store which is made attractive for two reasons. One, the idea of a conceptual store is in agreement with the notion of an "integrated store" (e.g. Connolly & Jones, 1970) indicating that somehow and somewhere an equivalence between sensory modalities must be stored. Two, the conceptual store is not restricted to the problem of an intermodality match but also implies any "abstract" that Ss are capable of having from a set of movements. For example, Levin, Norman and Dolezal (1973) showed that Ss are capable of constructing a concept of "an average of two movement lengths" and producing the average within the kinesthetic modality. Furthermore, Nacson et al (1972) also showed that Ss are capable of working with internally structured categories of movements. In addition the idea of a conceptual code can account for the dominant role of vision in the reproduction of movement information (Diewert, 1975; Wilberg & Girouard, 1975; Klein & Posner, 1974).

That encoding at the level of a conceptual code can produce better recognition does not appear unreasonable since it has been found in recall, that increasing information via additional auditory, visual, and heightened kinesthetic cues reduces recall errors (Adams, Marshall & Goetz, 1972; Stelmach & Kelso, 1975). Such

findings are generally interpreted as meaning that augmented feedback augments the strength of the perceptual trace (in Adams' terms, 1971). However Klein and Posner (1974, p. 404) have pointed out and shown that such a view might be too simple and may have to be tempered by considerations of the role of attention in processing (including encoding) the movement. Nevertheless, when several sources of information are available, whether a movement will be encoded at the level of a kinesthetic (perceptual) code, a dominant visual (perceptual) code, or a conceptual (mapping of both) code, will certainly depend on the task demands.

Finally, the concept of an episodic store may eventually lead to a better understanding of how order information (according to some spatial or temporal attributes) can be achieved since order information is an inherent feature of that store.

Perceptual and conceptual codes on one hand and conceptual and episodic stores on the other hand need not each correspond to independent physiological storage mechanisms. In fact they would best be viewed as being different in terms of depth of encoding or levels of cognitive organization (Craik & Lockhart, 1972; Restle, 1974). From the perceptual code to the format of the information within the episodic store, the information is only more complex.

From these distinctions Atkinson et al (1974) have developed a model to account for recognition latencies. They insist that their model must be regarded as a special case of more general theory of memory (Atkinson & Shiffrin, 1968). The model was developed to account first for long list of words (up to 60 words) stored in long-term store but a particular case is also made for search through short

list stored in the short-term store.

The model is presented in Figure 2 and its main elements are as follows. When a test stimulus is presented, it is encoded and mapped onto its conceptual code. The latter has a familiarity value about the test stimulus. If S finds a very high familiarity value he gives an immediate positive response; if he finds an extremely low value an immediate negative response is given. If the familiarity value is intermediate S must then take the test stimulus and scan it against the memory set in the short-term store. If the scan yields a match a positive response is made; otherwise a negative response is elicited. When the familiarity value is intermediate the speed of the response is much slower and depends on the number of elements in the memory set.

Thus for very high or very low familiarity values the Ss make a fast response that does not depend on the memory set size; for intermediate values a slower response occurs that is an increasing function of memory set size. The observed response latency averaged over trials is then a mixture of fast decision based on familiarity alone (independent of memory set size) and slower decision based on a search of the short-term store (dependent of the memory set size).

It is assumed that decision based upon familiarity will lead to a certain number of errors (false positive and false negative) whereas a search through short-term store will be slower but almost errorless. A mathematical model (Atkinson & Juola, 1974) as well as empirical evidence (e.g. Atkinson et al, 1974; Wescourt & Atkinson, 1976) have been presented in support of this model.

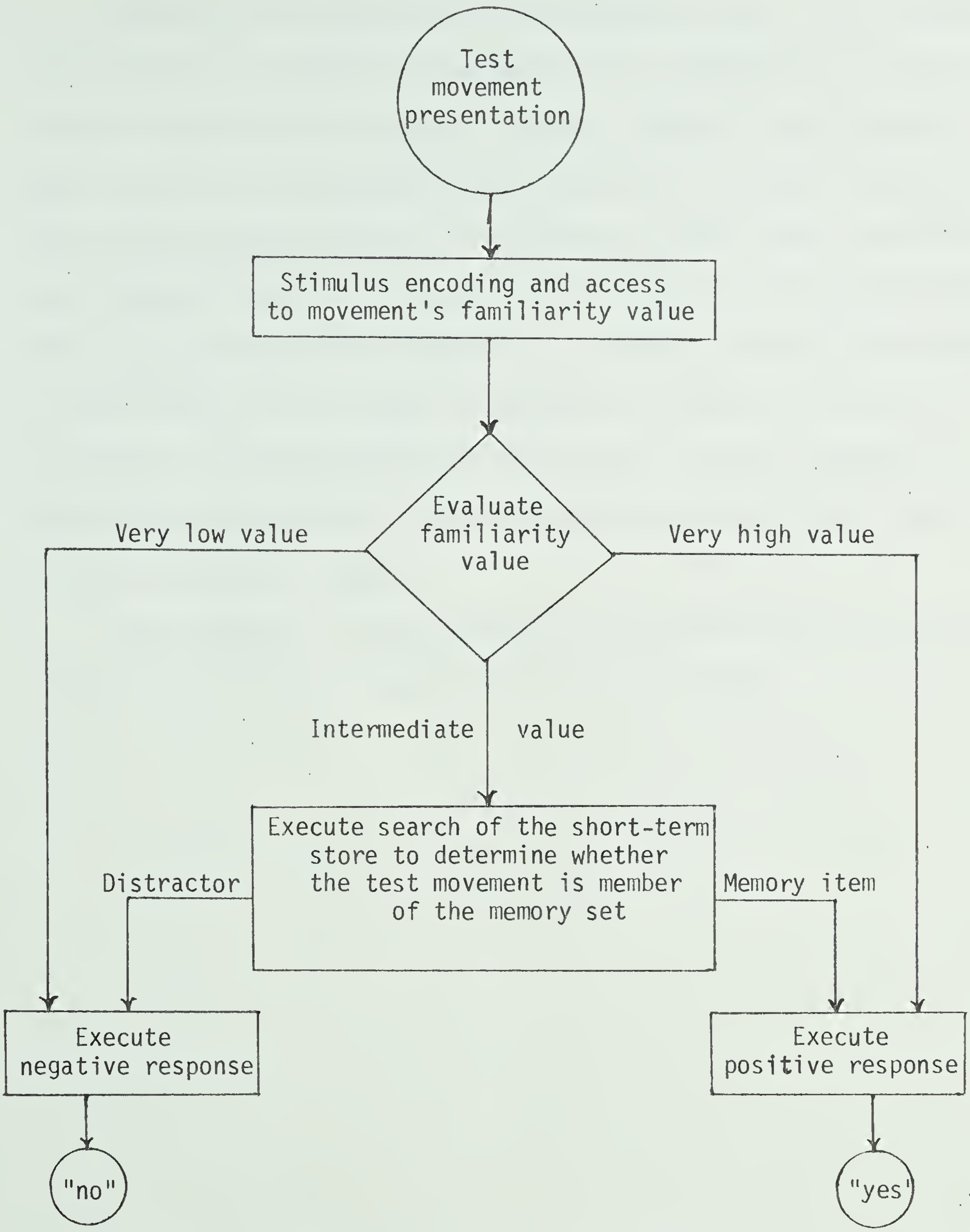

Figure 2. Flowchart representing the memory and decision stages involved in recognition (adapted from Atkinson & Juola, 1974).

Two points are worth noting concerning the model. One, Atkinson et al (1974) do not maintain the assumption of independence of stages and in fact found it to be untenable. Second, although that they found that the linear relationship between recognition latencies and memory set size was the best describing function for their data, they noted that this point was not critical in their model. In fact they noted that several alternative strategies are available to the Ss and whether or not there will be a search and whether the search will be serial or parallel, self-terminating or exhaustive, is simply dependent on the nature of the stimuli, the experimental conditions (e.g. repetitions or not) and the task demands.

Interpretations of the results of the present series of experiments will be made with that theoretical framework in mind.

Chapter 3

GENERAL METHOD

The purpose of the methodology that will be described is that of revealing some aspects of the memory processes by means of RT procedure in which a binary-classification task of recognition memory is used. Basically the general method is as follows. A set of _n_ different movements is presented to an S. Following a given period of time a test movement is presented and the S must respond as quickly as possible by pressing one of two keys indicating whether the test movement was part of the previously memorized set (positive response) or not (negative response). The general method is presented in this chapter. The details of the procedure as they were developed to meet the requirements of each experiment of this series are described before each experiment in the next chapter.

The task consisted of simple, linear, positioning movements (left to right abduction of the right arm in the horizontal plane) using a metal track and a slider moving freely along the track. The track was made up of a stainless steel rod 112 cm long by 1.5 cm diameter, mounted on a baseboard. A cursor, 3.9 cm long by 3.2 cm diameter, was fitted on the track such that it could be moved along the track with minimal friction. A small handle, 2.0 cm high was fixed at the top of the cursor. The displacement of the cursor activated a 10-turn potentiometer (Bourns, no. 35095-1-501) to which it was attached by means of a set of pulleys and wires. The output of the potentiometer

was then fed into a digital voltmeter (Keithley Instrument, model 168-22) which permitted a fast and accurate reading of the cursor positioning. The potentiometer was so calibrated that a displacement of 1 millimeter of the cursor was read as 1 millivolt on the voltmeter.

Two physical stops could be positioned anywhere on the track and were used to define the starting- and the end-location of all movements. The physical stops were of the same material and dimensions as those of the cursor. Each stop was positioned by a motor (Bodine Co., 1/15 h.p., 115 vac-28 rpm) to which it was attached by means of a set of pulleys and wires (see Figure 3: view of subject and apparatus).

A microswitch was fixed on the side of the physical stop that indicated the end of movements and wired so that when the cursor touched the stop, a digital millisecond timer (Marietta, model 14-15MS) was activated (in the case of the test movements only). The timer was stopped by having Ss to press one of two keys situated in front of them on their left. The keys (alternate push buttons) were inserted in a small box with the two keys located at the top of the box and being 3.0 cm apart. The left key was activated by the second finger of the left hand and was used to mean a positive response for half of the Ss and a negative response for the other half. The right key was activated by the forefinger of the left hand and was also used to mean a negative response for half of the Ss and a positive response for the other half. The roles of each key were thus counterbalanced in order to avoid any bias from using the same finger across all Ss to mean the same response.

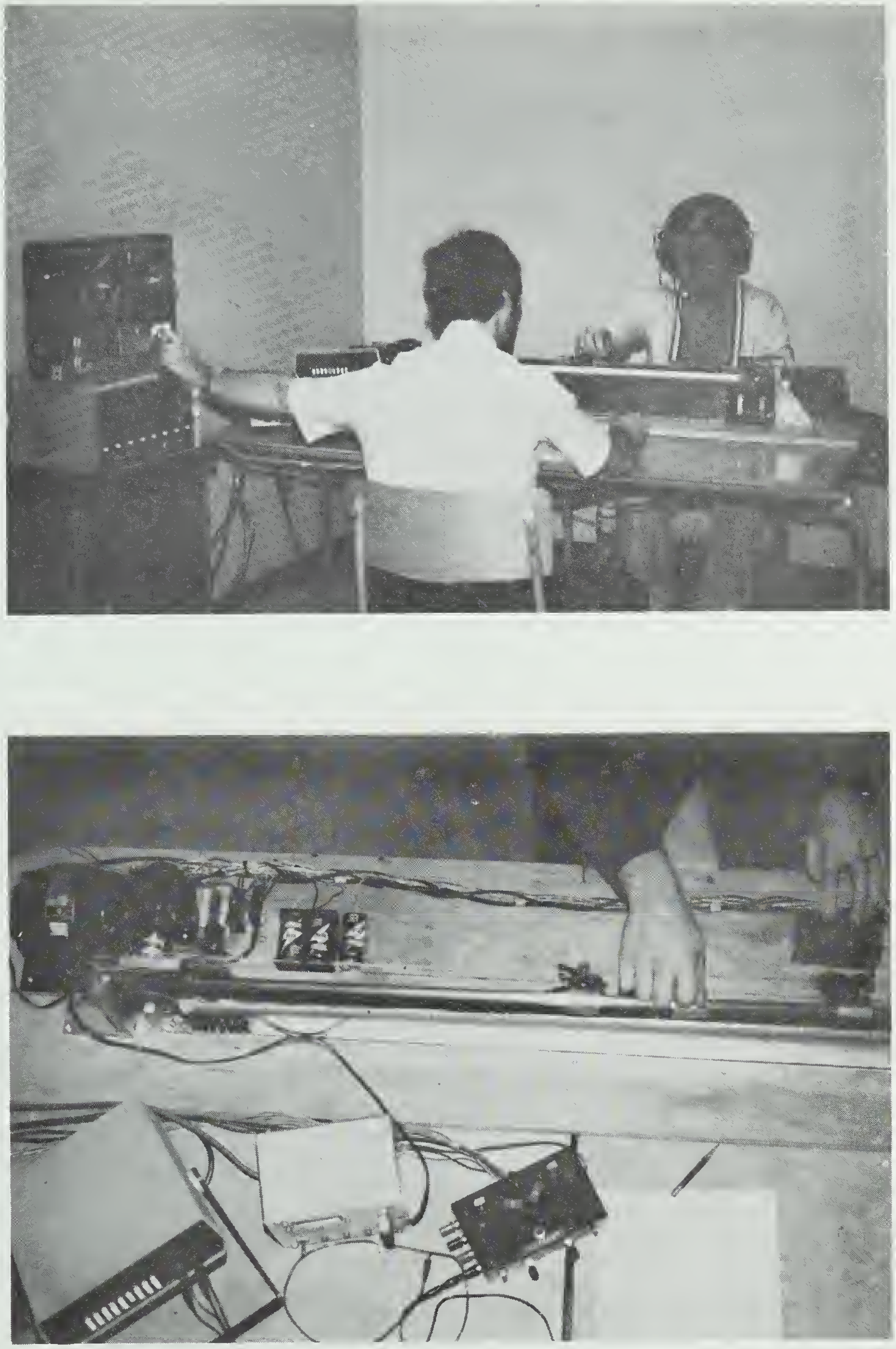

Figure 3: View of subject and apparatus.

In all cases throughout the experiments, movements were actively executed by the Ss. Finally, in order to eliminate any visual and auditory cues, Ss were blindfolded and wore earphones through which white noise was projected.

Chapter 4

METHOD, RESULTS AND DISCUSSION

Experiment I

Method

Purpose. The purpose of the first experiment was to determine the effects if any, of memory set size on the recognition process of three specific cues of movements: (a) their starting location, (b) end location, and (c) distance covered.

Stimulus material. A total ensemble of six movements (linear-positioning movements) entirely different from each other in terms of starting location (SL), distance (D), and end location (EL) were used in this experiment. A sub-set of three movements was used to construct memory sets of either 1, 2, or 3 movements (M = 1, 2, 3) for half of the Ss, the remaining three movements serving as distractors. For the other half of Ss, the memory movements and the distractors were reversed so that for the experiment as a whole, all movements were used equally often as memory movements or distractors. Table 14 in Appendix A describes the characteristics of the movements.

Design. There were four factors of immediate interest. The first factor was memory set size with three levels (M = 1, 2, 3 movements). It must be noted that this factor was determined from the fact that a linear relationship (i.e. M = 1, 2, 3) has been found between recognition RT and memory set size (Briggs & Blaha, 1969; Sternberg, 1969b) and that a logarithmic relationship (i.e. M = 1, 2, 4) is not necessarily the rule (Briggs & Swanson, 1970).

The second factor was movement cues with four levels. That factor was directly associated with the types of instruction that were given to the Ss as to which cue they had to recognize when the test movement was presented. The four movement cues were as follows. First, location-plus-distance information (D+L) was provided for which the Ss were asked whether or not D+L information present in the test movement was present in one of the movement of the memory set. This type of match implies a total recognition of the movement *per se* (i.e. when all cues are present) and was used as a control condition in this experiment.

For the remaining three movement cues, sets of movements were designed such that only one movement cue was made reliable in the test movement. Subjects were asked to recognize whether the given cue matched that of one of the memory movement or not. All test movements are illustrated in Table 8 in Appendix A. Therefore the second cue condition was D information for which Ss were asked if D information of the test movement matched D information of one of the memory movements. Third, EL information was questioned in a similar manner and fourth, SL information for which Ss had to recognize if the EL of the test movement corresponded to one of the SL of the memory movements.

The third factor was the types of response for which there were two levels: a positive response ("yes") and a negative response ("no").

Finally, the fourth factor with three levels represented each length categories of the memory and test movements that were used namely:

(a) short (median of 4.5 cm), (b) medium (median of 10.5 cm), and (c) long movements (median of 16.5 cm).

In summary, the design could be described as a 3 x 4 x 2 x 3 factorial experiment with three levels of memory set size, four levels of movement cues, two levels of responses, and three levels of movement lengths. A completely crossed within-S design was employed with repeated measures on all factors.

Subjects. Twelve male, undergraduate students ($\overline{X} = 23.2$ y.a., sd = 1.8) were recruited to participate in this experiment. They were paid $2.00 an hour for their participation.

Procedure. Each S performed 72 trials divided in three sessions of 24 trials each. Each session was held on a different day. Within each session memory set size was fixed. That is, M = 1, 2, or 3 for a given session and the order of presentation of this factor was counter-balanced for all Ss. All other factors were equally represented within each session. That is to say, there were 50% of each positive and negative trials, 25% of each type of cue trials and finally, an equal number of trials for each movement length. The order of presentation of the 24 trials was randomly selected for all Ss. The first session required approximately two hours and the other two sessions required one hour and a half each.

At the beginning of the first session, Ss first received written instruction (see Appendix B: Instruction to the subjects) and under-went a series of practice trials in order to fully understand the requirements of the task. Particularly, the instruction stressed: (a) the distinction between the four types of cues; (b) the meaning of

a positive and a negative response; (c) the fact that each response had to be fast; (d) the fact that within each session, there was an equal number of positive and negative responses. Following these instructions ten practice trials were given using verbal commands in order to practice the "yes-no" keys. Then ten practice trials were given utilizing memory movements and test movements different from those used in the experiment. Ss were then ready for the first 24 experimental trials.

Each trial was composed of the following events. The memory movement was presented by verbally asking the S to "grasp" the cursor and "move" it until it touches the physical stop, where he was asked to stay for three seconds (consequently all movements were E-defined). The S then moved back the cursor to its starting location. In the cases of M = 2 and M = 3, the same procedure was repeated with 10 seconds between each memory movement. Then S was instructed as to which cue was going to be recognized and the test movement was presented according to the same procedure. Concerning M = 2 and M = 3, the serial position of each movement in memory was counterbalanced. At the end of the execution of the test movement when the cursor hitted the stop, the timer so activated was stopped by the S pressing the "yes" or "no" key. The E recorded S's response and time and prepared the apparatus for the next trial. The inter-trial interval was 45 sec.

During the practice trials, Ss received feedback after each trial concerning the correctness and speed of their response but no such information was available after experimental trials.

<u>Dependent variables</u>. The only two dependent variables used were reaction-time data and response errors. Reaction time was the time that

elapsed from termination of the test movement (contact with the end stop) to key-pressing response. Response errors were S's responses that were incorrect (negative response when it was supposed to be a positive response, and the opposite). Since each of the 12 Ss performed 72 trials, a total of 864 responses and reaction-time data were collected and submitted to separate analyses of variance. A posteriori contrasts for each main effect were analyzed by means of Tukey (a) tests.

Results

Error scores. All 864 response scores (correct responses and errors) were submitted to a five-way analysis of variance (ANOVA) for repeated measure design. The summary of the analysis is contained in Table 1. From this analysis it was found that the distribution of errors was significant within two main factors: (a) memory set size (F (2,22) = 12.697, p < .01), and (b) movement cues (F (3,33) = 11.877, p < .01). There were no significant differences in terms of errors between the categories of movement lengths (F (2,22) = .562, p >.05) and the two types of responses (F (1,11) = 3.934, p >.05). In addition, two interactions were significant, a two-factor interaction between memory set size and movement lengths (F (4,44) = 4.015, p <.01) and a three-factor interaction involving memory set size, movement cues, and types of responses (F (6,66) = 3.100, p <.01).

From Table 2, it can be observed that recognition errors increase as a function of memory set size (M). Recognition errors were 32.99, 39.23 and 44.79 % for M = 1, 2 and 3 respectively. In fact, the

Table 1

Summary of the analysis of variance

on the error scores of Experiment I

Source	SS	df	MS	F
Subjects (a)	.846	11	.077	
Memory set size (j)	2.009	2	1.005	12.697**
a x j	1.741	22	.079	
Movement length (k)	.211	2	.105	.562
a x k	4.123	22	.187	
Movement cues (l)	6.050	3	2.017	11.877**
a x l	5.603	33	.170	
Responses (m)	3.501	1	3.501	3.934
a x m	9.791	11	.890	
j x k	2.741	4	.685	4.015**
a x j x k	7.509	44	.171	
j x l	1.260	6	.210	1.200
a x j x l	11.546	66	.175	
j x m	1.620	2	.810	3.166
a x j x m	5.630	22	.256	
k x l	1.669	6	.278	1.463
a x k x l	12.553	66	.190	
k x m	1.974	2	.987	3.328
a x k x m	6.525	22	.297	

** significant at the .01 level

Table 1 (cont'd)

Source	SS	df	MS	F
l x m	.235	3	.078	.259
a x l x m	9.973	33	.302	
j x k x l	3.907	12	.326	1.670
a x j x k x l	25.287	132	.192	
j x k x m	1.477	4	.369	1.784
a x j x k x m	9.106	44	.207	
j x l x m	3.463	6	.577	3.100**
a x j x l x m	12.287	66	.186	
k x l x m	2.442	6	.407	2.505
a x k x l x m	10.725	66	.162	
j x k x l x m	3.745	12	.312	1.144
a x j x k x l x m	36.005	132	.273	

** significant at the .01 level

Table 2

Mean percent of errors for each memory set size

as a function of the responses required

Memory set size (M)	Responses		Grand mean
	Positive	Negative	
M = 1	31.25%	34.72%	32.99%
M = 2	34.03%	44.44%	39.23%
M = 3	32.64%	56.94%	44.79%
Grand mean	32.64%	45.37%	39.01%

linear trend was found to be significantly positive ($F_{(1,22)}$ = 25.31, $p < .01$). In addition, a posteriori contrasts using Tukey (a) test revealed that one pair comparison (M = 1 vs M = 2) was significant at the $\alpha = .05$ level and that another pair comparison (M = 1 vs M = 3) was significant at the $\alpha = .01$ level. The last pair comparison (M = 2 vs M = 3) was not significant at the $\alpha = .05$ level (see: Appendix C, Table 19).

Concerning the types of responses, Ss made 32.64% of errors when a positive response was required as compared to 45.37% when a negative response was required (see: Table 2). In other words, Ss appeared to make more false positives (saying yes when they were supposed to say no) than false negatives (saying no when they were supposed to say yes). However, that difference was not significant as revealed by the ANOVA.

The interaction between memory set size and types of responses is interesting (see: Figure 4). Although the interaction was not significant in the ANOVA, the linear component of the interaction was significant ($F_{(1,22)}$ = 5.991, $p < .05$) indicating that the linear component of the trends of the memory set size effect for the two types of responses differed significantly. As it is apparent in Figure 4, false negative errors remained relatively constant over the different sizes of the memory sets while false positives increased as a linear function of memory set size. The increasing error rate as a function of memory set size observed previously could thus be attributed to an increase in false positive errors.

Concerning the movement cue effect, a posteriori contrasts (see: Appendix C, Table 19) revealed that there were no significant differences

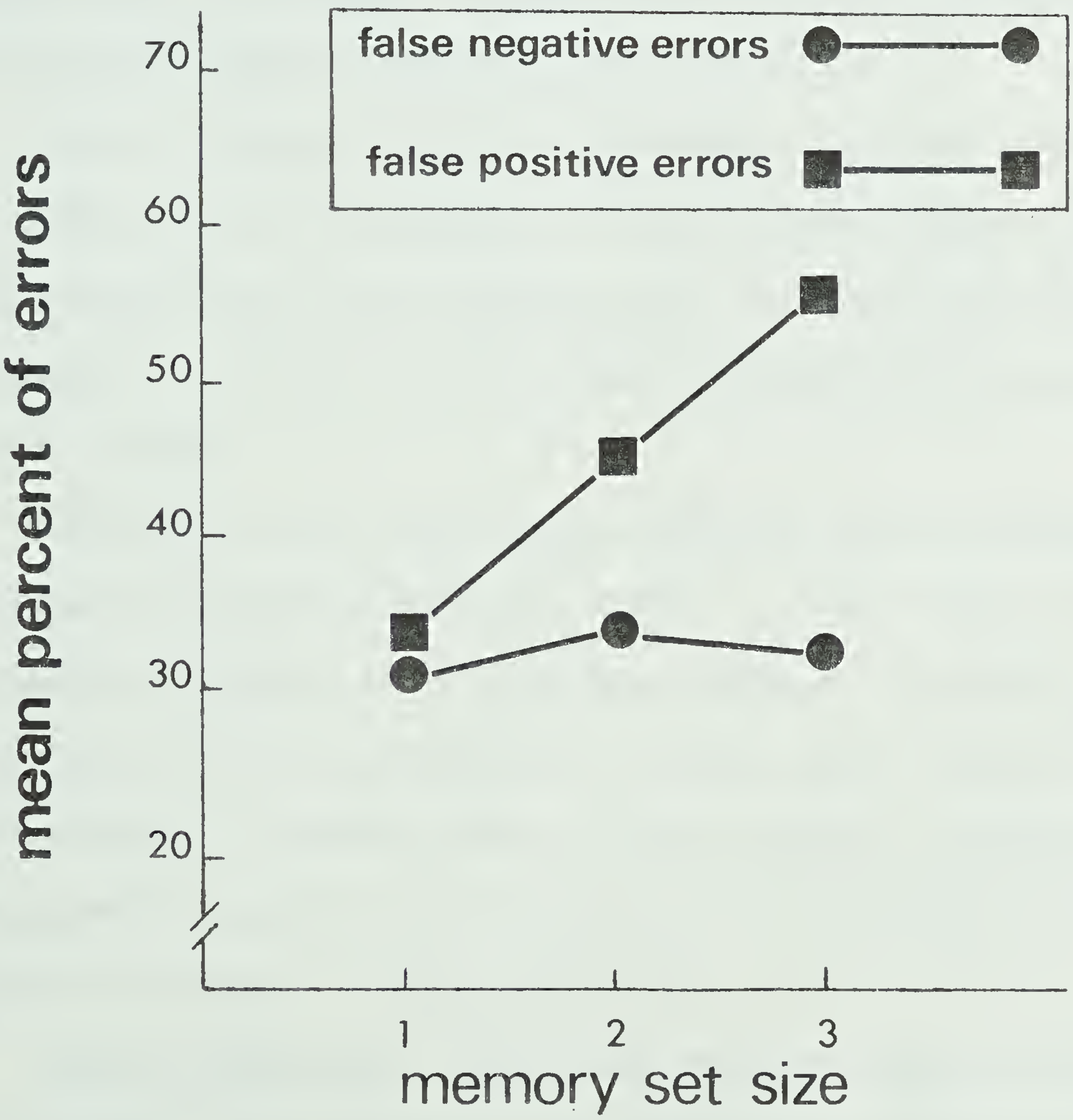

Figure 4. Mean percent of false positive and false negative errors as a function of memory set size. False negatives represent the errors that subjects committed by saying "no" when positive responses were required while false positives represent the errors when subjects said "yes" when negative responses were required.

between distance+location, distance, and end location information but that each of them was significantly different than starting location information at the α = .01 level. From Table 3, it can be observed that the highest error rate (52.32%) was in fact obtained with starting location information.

Concerning the movement length main effect, that factor was not significant in the ANOVA. Actual values of error rates for each movement length categories are displayed in Table 3.

Finally concerning the two interactions that were significant in the ANOVA, namely the memory set size x movement length interaction and the memory set size x movement cue x response interaction, no meaningful trends were apparent thus no further considerations will be given to them.

The overall error rate (false positives and false negatives all together) for the experiment was 39.01%. In other words, of the 864 responses collected, 337 of them were incorrect. Such error rate is much too high for a methodology as this one since reaction-time data must normally be obtained from an almost errorless performance. Consequently, reaction-time data that will be presented shortly will have to be interpreted very cautiously.

Reaction-time data. Before submitting the reaction-time data (RT) to an ANOVA, three operations were performed. Firstly, only RT for correct responses were analyzed which means that 39.01% of all RT were rejected. Secondly, the median RT was calculated for each S and for each experimental condition over the movement-length condition giving

Table 3

Mean percent of errors for each movement cue

as a function of movement length categories

Movement cue	Movement length			
	Short	Medium	Long	Grand mean
Distance+location	20.83%	34.72%	31.94%	29.17%
Distance	35.50%	35.50%	35.50%	37.50%
End location	44.44%	34.72%	31.94%	37.04%
Starting location	56.94%	54.17%	45.83%	52.32%
Grand mean	39.93%	40.28%	36.81%	39.01%

288 possible median RT. Twenty-two median RT were missing (7.65%) because there were no raw RT for correct responses in any movement length condition for a given S for a given experimental condition. Thirdly, missing median RT were estimated according to the method described by Winer (1962, p. 281) for a three-factor experiment. Each missing median RT was estimated, within each S, over the factors of memory set size, movement cues, and responses. The 288 median RT were then submitted to a four-way ANOVA with Ss serving as a fourth dimension.

The summary of the ANOVA on the RT data is contained in Table 4. None of the main factors (i.e., memory set size, movement cues, and responses) nor interactions reached the $\alpha = .05$ level of significance.

Mean RT for memory set size of 1, 2, and 3 movements were 704.20, 740.52, and 791.02 msec respectively. Although an increasing function was observed, the linear component of the set size effect was not significant ($\underline{F}\ (1,22) = 2.344$, $\underline{p} > .05$).

Positive responses tended to be, though not significantly, faster than negative responses. Actual mean RT were 726.60 and 763.89 msec for positive and negative responses. In addition, there was a slight tendency for mean RT to increase as a function of memory set size for both positive and negative responses (see: Figure 5).

Concerning the movement cue effect, actual mean RT are contained in Table 5 and the relationships between movement cues and memory set size are illustrated in Figure 6. Mean RT for distance+location, distance and end location cues are somewhat more similar to each other as compared to mean recognition RT for starting location cue (see: Table 5).

Table 4

Summary of the analysis of variance

on the reaction-time data of Experiment I

Source	SS	*df*	MS	*F*
Subjects (a)	19.069	11	1.734	
Memory set size (j)	.365	2	.183	1.186
a x j	3.386	22	.154	
Movement cues (k)	.780	3	.260	2.017
a x k	4.256	33	.129	
Responses (l)	.100	1	.100	.573
a x l	1.921	11	.175	
j x k	.593	6	.099	1.610
a x j x k	4.056	66	.061	
j x l	.022	2	.011	.035
a x j x l	7.127	22	.324	
k x l	.381	3	.127	1.450
a x k x l	2.890	33	.087	
j x k x l	.880	6	.147	.993
a x j x k x l[1]	6.538	44	.149	

[1]Twenty-two degrees of freedom were substracted from the 66 *df* of the mean square error of the three-factor interaction due to the 22 median RT that were estimated as a method of replacement of the missing median RT.

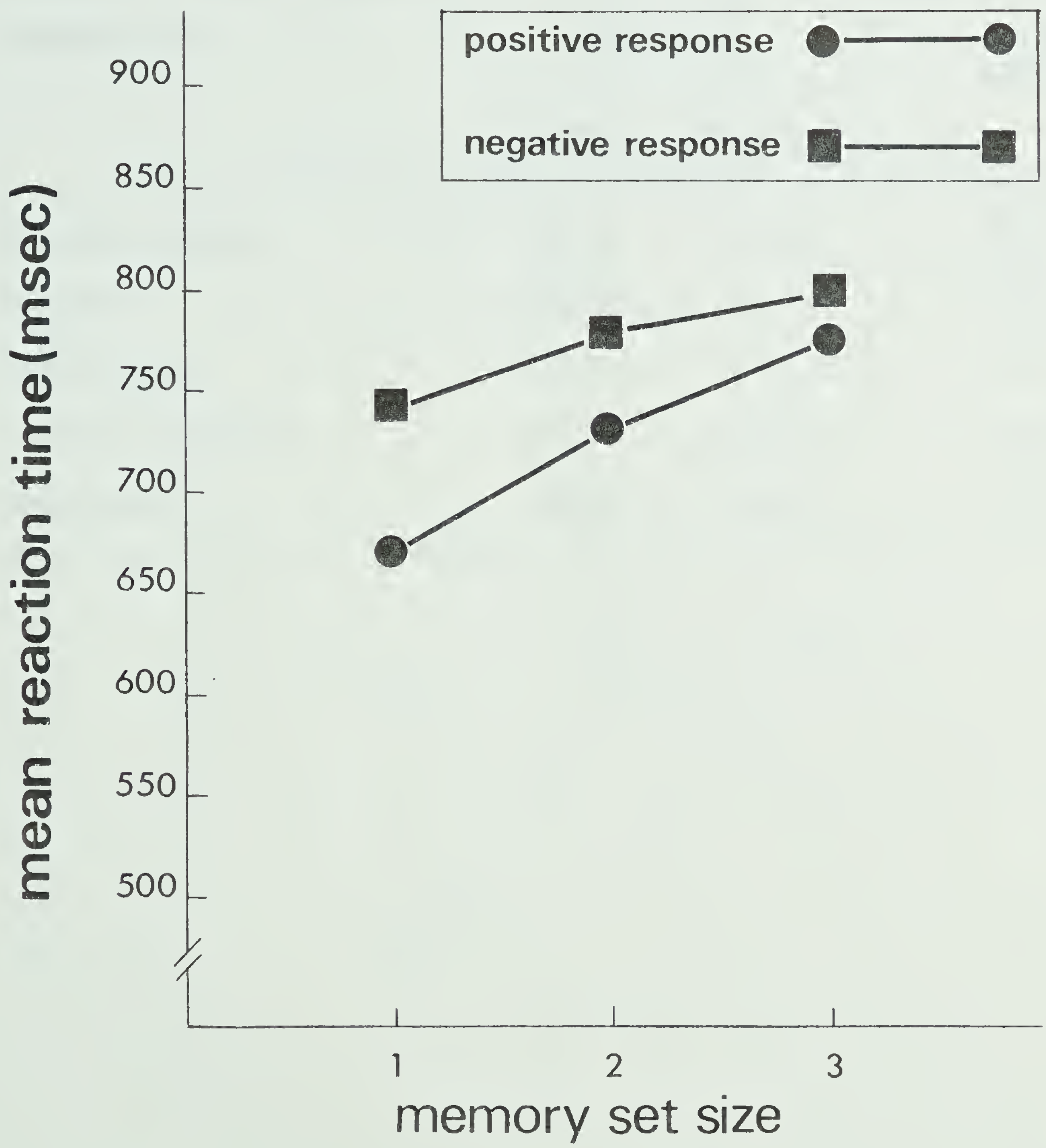

Figure 5. Mean reaction time for positive and negative responses as a function of memory set size.

Table 5

Mean reaction time (in msec) as a function

of movement cue for each type of response

Movement cue	Responses		Grand mean
	Positive	Negative	
Distance+location	666.78	805.03	735.90
Distance	728.78	680.28	704.53
End location	713.75	701.58	707.67
Starting location	797.11	868.67	832.89
Grand mean	726.60	763.89	745.25

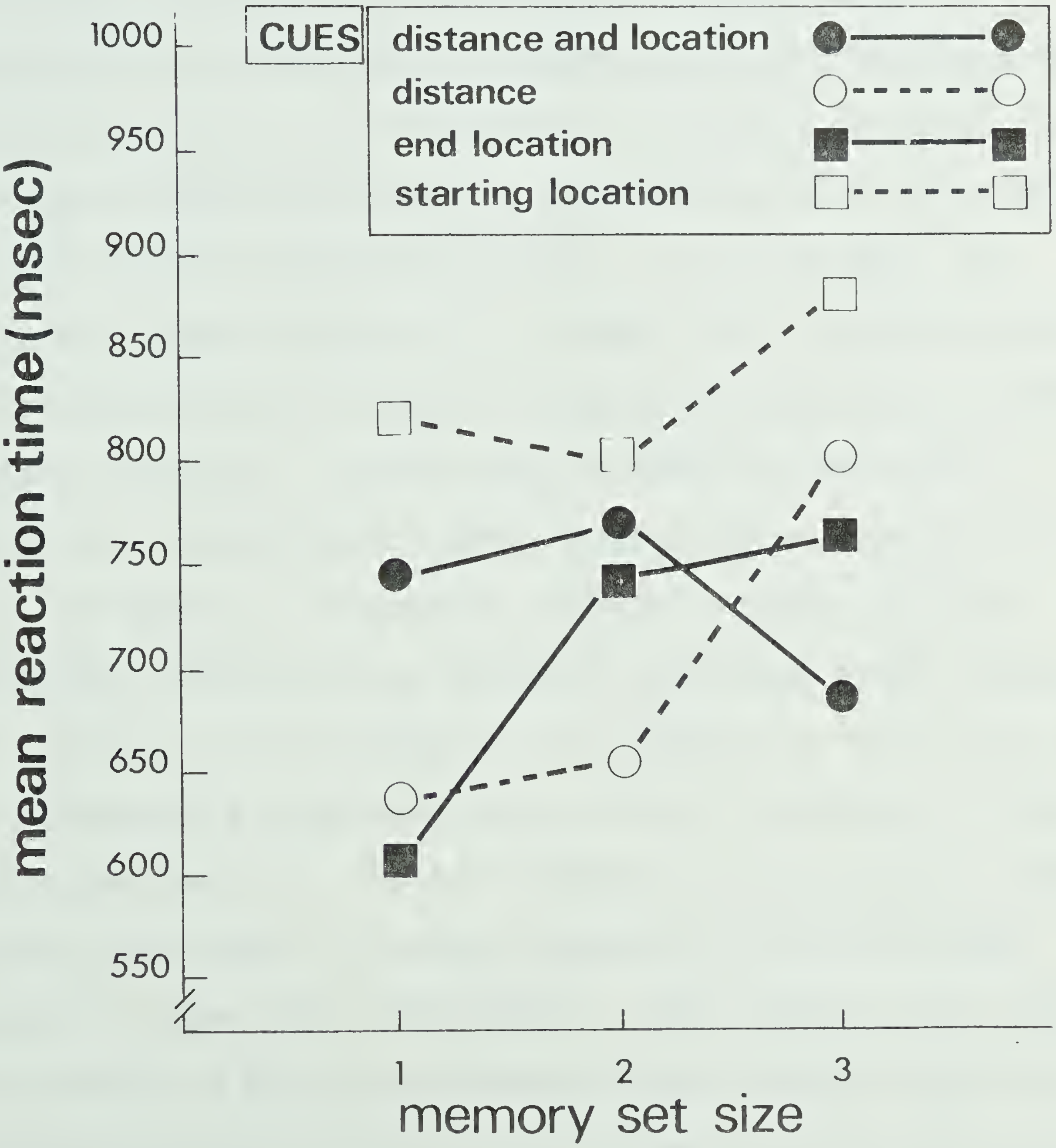

Figure 6. Mean reaction time as a function of memory set size for each movement cue.

Discussion

The absence of any effects on recognition RT are probably due to such a high error rate obtained in this experiment. For example, we have observed the tendency for recognition RT to increase as a function of memory set size. At the same time, recognition errors increased significantly as a function of the same factor. If recognition performance would have been almost errorless, that is to say small and unsignificant number of errors at each level of set size, significant differences on recognition RT as a function of set size might have been observed. In this experiment, the procedure seemed to force the Ss to adopt fairly consistent speed of responses but at the expense of more errors under certain experimental conditions. In other words, Ss seemed to have adopted speed-accuracy trade-offs favoring speed at the expense of errors.

The tendency of the results obtained on recognition RT are consistent with the results reported in the verbal memory literature. For example, we have already noted the tendency for recognition RT to increase as a function of memory set size. Significant effects on recognition RT as a function of memory set size have been reported in the verbal memory literature (Sternberg, 1966, 1969a, 1969b; Swanson & Briggs, 1969; Kristofferson, 1972; Clifton & Tash, 1973). In addition, we have observed that positive responses tended to be slightly faster than negative responses which has also been constantly reported in the verbal memory literature (Sternberg, 1966; Anders et al, 1972; Dardley et al, 1972; Lively, 1973).

However, due to the error rate observed discussion about recognition RT beyond this point would perhaps be too speculative. Therefore the discussion will now be focussed on the recognition error data.

Memory set size. We have observed a significant linear relationship between recognition errors and memory set size. This is consistent with the recall of movement information. For example, Wilberg and Salmela (1973) found that absolute and variable errors at recall were significantly augmented as a function of memory set size for sets of size 2, 4 and 8 movements. In a similar way, Stelmach and Bruce (1970) found that absolute errors were significantly greater for the recall of three movements than for one movement. In this respect, recognition and recall of movement information behave in the same way both being similarly affected by memory load. This is entirely consistent with the conclusions presented by Kintsch (1970) for verbal recognition and recall as far as memory set size is concerned.

False positive and negative errors. We found that the increasing number of recognition errors as a function of memory set size was mostly due to an increase of false positive errors, that is to say, an increasing tendency to recognize a distractor as a memory movement. This is also entirely consistent with what has been found in verbal memory literature (Wickelgren & Norman, 1966; Kausler, 1974; Cregg, 1976). Cregg (1976) in particular found that false positives increased as a function of retention intervals. Concerning movement information, we can only speculate as to why this happens since we have no firm evidence for a

decay and/or interference explanation of forgetting in STMM. In the methodology that we have used, memory set size and retention interval covaried since time per movement in memory was fixed. Therefore, a decay process of the memory traces of the movements, interference effects among the memory traces, an interference between memory traces and the representation of the test movement in the test phase, or a combination of those reasons could be responsible for the increase in false positives. McCormack and Swenson (1972) argued that false positives in a verbal paradigm arise from interference originating in the test phase. The present experiment was not designed to test such possibilities and therefore no conclusive statement can be reached except to acknowledge the same effect of increasing false positives as that observed in verbal memory.

Movement length. We found that as movement length increased Ss committed, though not significantly, less recognition errors. Same but significant effects have been reported by Marshall (1972) and Kantowitz (1974). It is interesting to note the opposite trends between recognition and recall of movement information. Concerning recall it has been found that the longer the movement the greater the absolute error at recall (Adams & Dijkstra, 1966; Marshall, 1972) while in recognition, the longer the movement, the smaller the number of recognition errors. In other words, longer movements seem to be best recognized but most poorly recalled. The reasons why this would be so are still not clear. It could just be an artifact of indexing memory performance: percent of errors for recognition and absolute or variable errors for recall of movement information. It could be due to an effector problem: that of greater problem of executing long as opposed to short movement

during the test phase of a recall paradigm. It could also be due to a real memory problem. More research are needed on this point.

Movement cues. The highest error rate was observed for the recognition of starting location information. Two possibilities could explain such a high error rate for that movement cue. One, it could be that starting location was in fact the most difficult cue to encode and/or memorize. Two, it could be due to a difficulty associated with the procedure that was used. It must be remembered that the question was: "tell me if, yes or no, the end location of the next test movement correspond to one of the starting locations of the movements you have memorized before". So Ss had to translate SL into EL or vice versa and subjective reports as well as objective error rates indicated that it was the most difficult experimental condition. In fact for the other three movement cues (D+L, D, and EL), there was no such translation to do and the error rates for each cue were not significantly different from each other. Whether such a high error rate for starting location reflected a real recognition problem or a difficulty associated with the procedure will have to be tested in future experiment.

The absence of significant differences in terms of recognition errors between D and EL information were surprising since on the basis of the literature on motor recall of E-defined movements, recall based on EL information has produced better performance than recall based on D information (Marteniuk & Roy, 1972; Keele & Ells, 1972; Laabs,1973, 1974; Stelmach & Kelso, 1973; Diewert, 1975). Concerning the distinction between D+L and EL information, the latter has yielded significant greater variable error than the former in a recall paradigm (Keele & Ells, 1972). In the present experiment no differences were found between

both. It must be added that the same trend was found in this experiment as that found in the motor recall literature: recognition performance was slightly worse for D than for EL information which in turn was slightly worse than for D+L information. However, the trend was not significant in the present experiment while it was in recall studies.

Based on the assumption that a recognition paradigm can particularly be sensitive to encoding and storage processes, the contention that D and EL information do have different encoding and memory characteristics (Marteniuk *et al*, 1972; Marteniuk, 1973; Stelmach *et al*, 1975) does not appear to be substantiated in the present experiment.

Experiment II

Method

Purpose. The purpose of the second experiment was to determine the effects if any, of the locus of the instruction to cue on specific attributes of movements. The aim was to determine if there were any differential effects on recognition latencies between giving the cue before storing the information in memory and after it was stored (before the presentation of the memory movement in the former case and just prior recognition in the latter).

Stimulus material. Only one memory movement ($M = 1$) and one distractor were selected for this experiment and what was the memory movement for half of the Ss was the distractor for the other half and vice versa so that across Ss a movement was used an equal number of time as memory movement and distractor. The nature of the memory items, distractors and test movements used in this experiment are described in Table 15 (Appendix A).

Apparatus and task. The apparatus and the task were in all respects identical to what was used in Experiment I with the exceptions: (a) that only one memory set size was used ($M = 1$), (b) Ss were instructed either before or after the presentation of the memory movement which cue was going to be tested.

Design. A 2 x 4 x 2, completely crossed, factorial design with repeated measures on all factors was used in this experiment. The first factor was the locus of instruction with two levels: (a) before (precuing condition) and, (b) after (postcuing condition) the presentation of the memory movement. The second factor was the four types of cues which were the same ones as those already described in Experiment I. The third factor was the types of response with two levels, either positive or negative.

Subjects. Sixteen male, undergraduate students ($\overline{X} = 22.6$ y.a., sd $= 2.1$) were recruited for this experiment. All Ss were different from those who participated in Experiment I. Since this experiment required only one session of approximately 70 minutes per S, Ss were not paid for their participation.

Procedure. Each S performed 16 trials representing one trial for each treatment combination. The order of the treatment combination was randomly selected for all Ss.

At the beginning of the session, Ss received written instruction and underwent a series of 15 practice trials with movement items different from those used in the experiment. The written instruction was similar, with appropriate modification to that used in Experiment I.

The first instance of a trial was as follows. The memory movement was presented by verbally asking the S to "grasp" the cursor and to "move" it until he hit the physical stop where he was asked to stay for three seconds. Following that period of time he was asked to "move back" to the starting location. Then S was instructed as to which cue was going to be recognized and the test movement was presented according to the same procedure. The way of responding "yes" or "no" by pressing one of the two keys at the end of the execution of the test movement was identical to Experiment I.

In the second instance of a trial, S was not instructed before the introduction of the memory movement. The instruction was given just before the presentation of the test movement. The remainder of the procedure was the same as that of Experiment I.

Dependent variables. Again, the only two dependent variables of interest were reaction-time data and response errors.

Results

Errors scores. The 256 responses collected (correct responses and errors) were submitted to a four-way ANOVA of which a summary is presented in Table 6. Only one main effect, namely movement cue was significant (F (3,45) = 4.992, $p < .01$). Loci of instruction (F (1,15) = 1.771, $p > .05$), types of responses (F (1,15) = .018, $p > .05$) as well as all interaction terms did not reach the $\alpha = .05$ level of significance.

Tukey (a) test was used to compare pairs of means concerning the movement cue main effect. Only one pair comparison was significant at the $\alpha = .01$ level, namely starting location versus distance + location information (see: Table 20 in Appendix C). Actual mean

Table 6

Summary of the analysis of variance

on the error scores of Experiment II

Source	SS	df	MS	F
Subjects (a)	1.809	15	.121	
Loci (j)	.191	1	.191	1.771
a x j	1.621	15	.108	
Movement cues (k)	3.355	3	1.118	4.992**
a x k	10.082	45	.224	
Responses (1)	.004	1	.004	.018
a x 1	3.309	15	.221	
j x k	.230	3	.077	.606
a x j x k	5.707	45	.127	
k x 1	1.230	3	.410	1.398
a x k x 1	13.207	45	.293	
j x 1	.004	1	.004	.032
a x j x 1	1.809	15	.121	
j x k x 1	.043	3	.014	.109
a x j x k x 1	5.895	45	.131	

** significant at the .01 level

values of recognition errors for each movement cue are presented in Table 7 from which it can be observed that Ss committed the least errors when D+L information were available for recognition (10.94%) while they committed the most errors when they had to recognize starting location information (42.19%). Recognition of distance (28.13%) and end location information (20.31%) displayed intermediate values of errors. The overall error rate for the Experiment was 25.39%.

Reaction-time data. Only reaction-time for correct responses were kept. Missing RT (25.30%) were estimated according to the method described by Winer (1962, p. 281) for a three-factor experiment. Each RT was estimated, within each S, over the factors of loci of instruction, movement cues, and responses. The 256 raw RT were then submitted to a four-way ANOVA, Ss serving as a fourth dimension.

The summary of the ANOVA is presented in Table 8. None of the main factors nor interactions reached the $\alpha = .05$ level of significance. Actual mean values of the different experimental conditions are presented in Table 9. Recognition RT for EL, D, D+L and SL were respectively of 698.92, 715.92, 747.31 and 798.91 msec. Negative responses (701.02 msec) tended to be slightly faster than positive responses (779.52 msec). The precuing condition (729.59 msec) produced slightly faster recognition RT than the postcuing condition (750.95 msec).

Discussion

As was the case in Experiment I, absence of any effects on recognition RT might still be due to a relatively high error rate in this experiment. Although the overall error rate was somehow lower in this experiment (25.39%) relative to Experiment I (39.01%), no effects were

Table 7

Mean percent of errors for each movement cue as a function of the loci of instructions and the responses required

Movement cue	Loci of instructions: Before, Positive response	Before, Negative response	After, Positive response	After, Negative response	Grand mean
Distance+location	12.50%	12.50%	12.50%	6.25%	10.94%
Distance	25.00%	18.75%	37.50%	31.25%	28.13%
End location	25.00%	6.25%	31.25%	18.75%	20.31%
Starting location	31.25%	50.00%	31.25%	56.25%	42.19%
Grand mean	23.44%	21.88%	28.13%	28.13%	
Grand mean	22.66%		28.13%		25.39%

Table 8

Summary of the analysis of variance

on the reaction-time data of Experiment II

Source	SS	df	MS	F
Subjects (a)	9.577	15	.638	
Loci (j)	.029	1	.029	.285
a x j	1.536	15	.102	
Movement cues (k)	.371	3	.124	.630
a x k	8.810	45	.196	
Responses (l)	.394	1	.394	1.952
a x l	3.030	15	.202	
j x k	.290	3	.097	1.378
a x j x k	3.156	45	.070	
j x l	.090	1	.090	1.342
a x j x l	1.005	15	.067	
k x l	.072	3	.024	.344
a x k x l	3.147	45	.070	
j x k x l	.207	3	.069	1.165
a x j x k x l[1]	2.672	45	.059	

[1] sixty-five degrees of freedom should be substracted from the 45 df of the three-factor error term due to the 65 raw RT that were estimated as a method of replacement of the missing data.

Table 9

Mean reaction time (in msec) for each movement cue as a function of the loci of instructions and the responses required

Movement cue	Loci of instructions				
	Before		After		
	Positive response	Negative response	Positive response	Negative response	Grand mean
Distance+location	787.75	704.69	827.56	669.25	747.31
Distance	674.50	683.50	855.44	650.25	715.92
End location	780.81	697.31	649.81	667.75	698.92
Starting location	757.31	750.81	902.94	784.56	798.91
Grand mean	750.09	709.08	808.94	692.95	
Grand mean	729.59		750.95		740.27

noted in terms of recognition RT. Recognition errors will first be discussed.

Loci of instruction. In Experiment I, a postcuing technique was employed: Ss knew only after they had memorized the movements which cue had to be recognized. It was felt that such technique could partially be responsible for the error rate observed and so the purpose of this experiment was to compare a precuing and a postcuing condition. The precuing condition did not significantly reduce the number of recognition errors.

One possible reason could be that in the postcuing condition, Ss encoded all cues (D+L, D, EL, and SL) and were therefore ready for being tested on any one of them. Hagman and Francis (1975) have shown that Ss are capable of encoding D, EL, and D+L at the same time and can immediately reproduce any one of them accurately. If so, that would explain the equivalence between precuing and postcuing conditions. In a precuing condition, Ss encode only the movement attribute for which they are cued. In a postcuing condition, Ss encode all necessary attributes and are therefore ready to be tested on any one of them. Recognition performance was of equal accuracy in both conditions. Consequently, reduction of the overall error rate will have to be reached by other means and among them, by rendering memory movements and distractors more dissimilar from each others.

Movement cues. In comparing results from Experiments I and II, the same pattern of distribution of recognition errors among movement cues emerges: the least errorful cue was D+L successively followed by EL, D, and SL cues with no significant differences between the first

three movement cues. Concerning D+L, EL, and D, although there might be some differences in the efficiency of reproduction motor memory depending on which cues Ss are working with (Marteniuk & Roy, 1972; Marteniuk _et al_, 1972), there do not seem to exist any differences in recognizing those cues.

Types of responses. Results of both Experiment I and II were fairly consistent in this respect: no significant differences between recognition errors for positive and negative responses.

Recognition reaction-time. The same trends were noted between the results of Experiment I and II: very slight differences between recognition RT of D and EL information which were both slightly faster than D+L information which in turn was slightly faster than SL information. For both recognition errors and RT there were no significant differences between D, EL, and D+L for Experiment I and II.

Contrarily to Experiment I, negative responses tended to be slightly faster than positives responses. That result was somewhat surprising since a fixed-set procedure was used in this experiment (the same memory movement was used over successive trials) and only one size of memory set (M = 1) was employed. In such cases positive responses are normally significantly faster than negative responses (Posner & Mitchell, 1967; Nickerson, 1973; Briggs & Blaha, 1969; Miller & Pachella, 1973). The absence of significant effects of types of responses on recognition RT could of course be attributed to the high error rate of this experiment.

In summary, whether or not Ss knew in advance which cue had to be recognized did not affect recognition performance of movement information. Therefore, reducing the error rate in this type of paradigm will have to be achieved by a different means, for example by rending the memory

and the distractor movements more dissimilar from each others. Nevertheless, considering the overall error rate, recognition performance both in terms of errors and RT were very similar for D+L, D, and EL information.

Experiment III

Method

Purpose. The purpose of the third experiment was to determine the effects if any, of a retention interval on the recognition process of movement information. Particularly, on the recognition process based on two specific cues of movement, the end location and the distance covered. The aim was to determine if there were any differential effects between: (a) immediate recognition, (b) recognition after an unfilled retention interval, (b) recognition after a retention interval filled with an attention-demanding task.

Stimulus material. A total set of six movements (linear-positioning movements) entirely different from each other in terms of their SL, D, and EL were used in this experiment. A sub-set of three movements was used as memory movements while the sub-set of the remainder three movements was used as distractor for half of the subset. For the other half of the Ss, the contents of the two sub-set were simply interchanged such that any given movement served equally often as memory movement and distractor. Table 16 (Appendix A) describes the nature of the memory movements, distractors, and test movements used in this experiment. It can be observed from Table 14, 15, and 16 that movements which constituted total ensembles for Experiment I, II, and III were made more dissimilar as the research progressed from the first to last experiment.

Apparatus and task. The apparatus and task were in all respects identical to what was used in Experiment I with the following exceptions: (a) only one memory set size was used ($M = 1$), and (b) three different types of retention intervals were presented to the Ss.

Design. A 2 x 3 x 2, completely crossed, factorial design with repeated measures on all factors was used in this experiment. The first factor was the type of cues with two levels: (a) recognition based on distance information, and (b) recognition based on end-location information. The second factor was the three types of retention intervals: (a) recognition after a 0 sec retention interval, (b) recognition after a 20 sec unfilled retention interval, and (c) recognition after a 20 sec retention interval filled with a mental interpolated task. The length of the retention interval was choosen such as to permit comparison with studies on motor recall in which a 20 sec retention interval was used (Posner 1967b; Stelmach & Walsh, 1973; Marteniuk, 1973). The interpolated task was also identical to that used in many studies on motor recall (Posner & Konick, 1966; Posner, 1967b; Keele & Ells, 1972).

Subjects. Twelve male, undergraduate students ($\overline{X} =$ 21.5 y.a., sd $= 2.56$) were recruited to participate on a voluntary basis in this experiment. All Ss were different from those who participated in either Experiment I or II.

Procedure. Each S received 12 trials representing one trial for each treatment combination. The order of presentation of the 12 treatment conditions was randomly selected for each S. Only one session was required for each subject.

At the beginning of the testing session, the Ss received written instruction and underwent a series of 12 practice trials with movements different from those used in the experiment. The written instruction was similar with appropriate modification to that used in Experiment I.

The procedure used in this experiment was identical to that used in the first two experiments with the following adaptation. At the end of the execution of the memory movement, S disengaged his hand from the cursor which allowed the E to reset the apparatus appropriately for the next test movement. Following this, the E gave the verbal command "regrasp the cursor". When that command was executed, E then activated an interval timer which was connected to a sound generator. The resulting tone indicated the moment at which the test movement was to be initiated. There were three possibilities: (a) the tone came on immediately which indicated to S to initiate the test movement (0 sec retention interval), (b) the tone came on only after a delay of 20 sec during which the instruction asked S to concentrate his attention on the to-be-recognized information, (c) the tone came on only after a delay of 20 sec during which the mental interpolated task was executed.

The interpolated task was a condensation task in which any digits presented (number between 1 and 99) had to be classified as odd or even and below or above 50. Numbers, in a random orders were registered on a tape recorder and presented at a rate of one every two seconds. Instruction given to the Ss stressed the importance of the interpolated task and Ss were told that errors made on this task were recorded. Results on this task are presented in the next section. The remainder of the procedure was the same as that of Experiment I.

This meant that a postcuing procedure was used.

Dependent variables. The two dependent variables were reaction-time data and response errors.

Results

Interpolated task. On the average, each S committed 1.2 errors (3.2% of errors) in classifying into one out of four possible categories all digits presented to them during the retention intervals. Therefore it can be assumed that Ss paid careful attention to the accomplishment of the interpolated task.

Error scores. Concerning the error frequencies during the realization of the main recognition task, 15.97% of all Ss' responses were errors as compared to error rates of 39.01% and 25.39% in Experiment I and II respectively. From an analysis of variance of the error scores it was found that none of the main effects nor interactions reached the $\alpha = .05$ level of significance. A summary of this analysis is presented in Table 10.

In Table 11, group means for the different experimental conditions are presented. From this table it can be observed a slight tendancy for recognition errors to increase as a function of the difficulty of the retention intervals. Percentage of recognition errors were nearly equals for positive and negative responses as well as for distance and end location information. Figure 7 illustrates the fact that false negative errors were stable while false positive errors tended to increase as a function of the difficulty of the retention intervals.

Reaction-time data. Only RT for correct responses were kept. Missing RT (15.97%) were again estimated according to the method described by Winer (1962, p. 281) for a three-factor experiment.

Table 10

Summary of the analysis of variance

on the error scores of Experiment III

Source	SS	df	MS	F
Subjects (a)	1.743	11	.158	
Movement cues (j)	.007	1	.007	.054
a x j	1.410	11	.128	
Retention intervals (k)	.264	2	.132	.946
a x k	3.069	22	.140	
Responses (l)	.007	1	.007	.186
a x l	.410	11	.037	
j x k	.181	2	.090	.478
a x j x k	4.153	22	.189	
j x l	.063	1	.063	.673
a x j x l	1.021	11	.093	
k x l	.264	2	.132	.946
a x k x l	3.069	22	.140	
j x k x l	.125	2	.063	.388
a x j x k x l	3.542	22	.161	

Table 11

Mean percent of errors for each retention interval condition as a function of the movement cues and the responses required

Retention intervals	Movement cues				
	Distance		End location		
	Positive response	Negative response	Positive response	Negative response	Grand mean
0 sec	16.67%	8.33%	16.67%	0.00%	10.42%
20 sec unfilled	16.67%	8.33%	16.67%	25.00%	16.67%
20 sec filled	25.00%	25.00%	8.33%	25.00%	20.83%
Grand mean	19.44%	13.89%	13.89%	16.67%	
Grand mean	16.67%		15.28%		15.97%

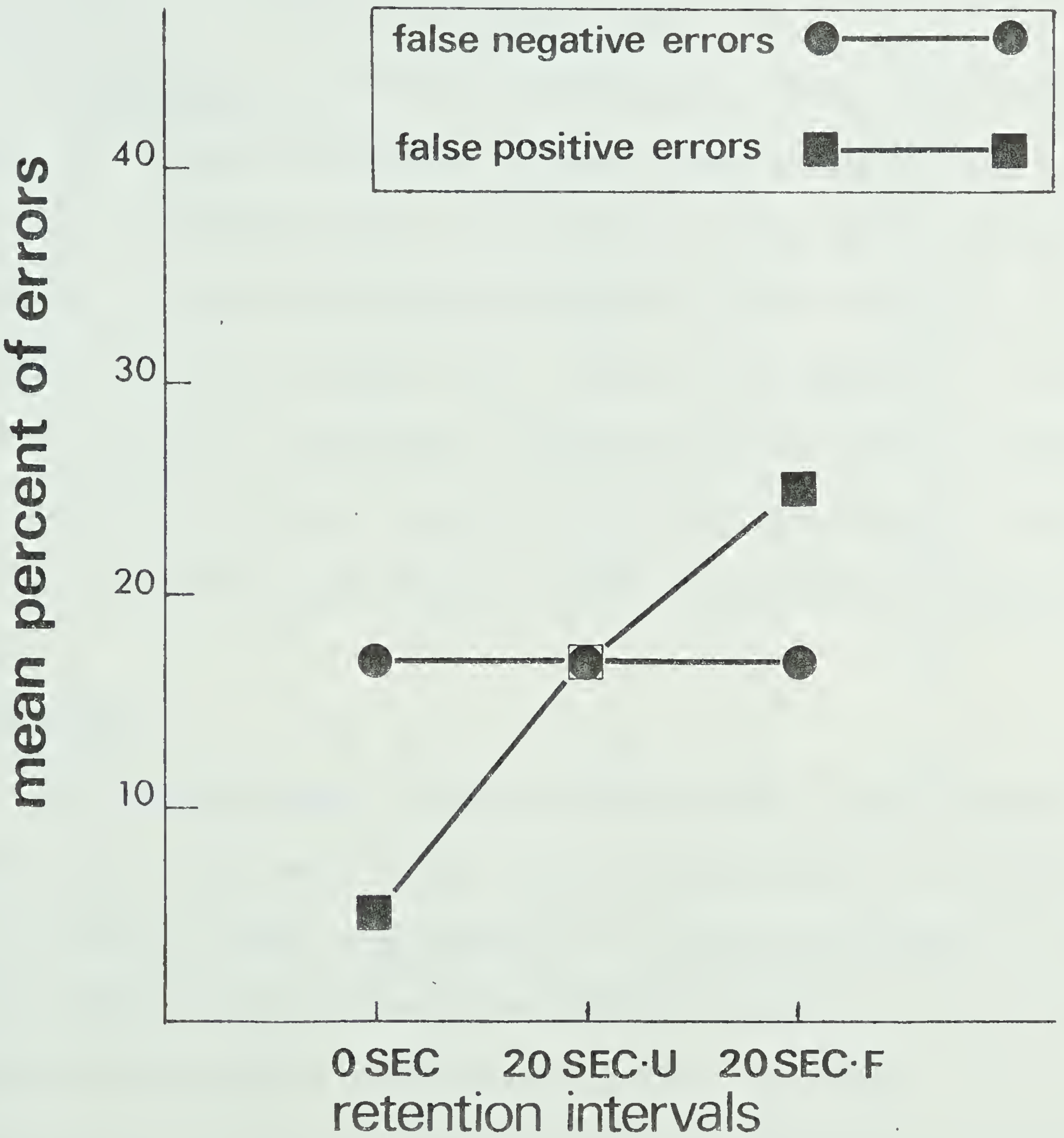

Figure 7. Mean percent of false negative and false positive errors as a function of retention intervals. False negatives represent the errors that subjects committed by saying "no" when positive responses were required while false positives represent the errors when subjects said "yes" when negative responses were required (Note: 20 sec-U: 20 sec unfilled; 20 sec-F: 20 sec filled with an interpolated task).

Each RT was estimated, within each S, over the factors of movement cues, retention intervals, and responses. The 144 raw RT were then submitted to a four-way ANOVA, Ss serving as a fourth dimension.

The summary of the ANOVA is presented in Table 12. Only one main effect was significant. That was the retention interval conditions (F (2,22) = 3.779, p < .05). No other main effects nor interactions reached the α = .05 level of significance.

A posteriori contrasts tested by means of Tukey (a) tests revealed that only one pair comparison was significant at the α = .05 level. That is, recognition RT was significantly longer after a 20 sec retention interval filled with an attention-demanding task than after a 20 sec unfilled retention interval (see: Table 21 in Appendix C). Group means for the different experimental conditions are presented in Table 13. Again in this experiment, negative responses (575.78 msec) were found to be, though not significantly, faster than positive responses (648.29 msec).

Discussion

By rendering memory movements and distractors more dissimilar from each others, the overall error rate has been reduced to 15.97% which is in fact the lowest one observed in all three experiments. Errors were evenly distributed among the different experimental conditions since no main effects nor interactions were significant. From those two results, it can be considered that the obtained RT data are somehow more meaningful than in the previous two experiments.

Concerning recognition errors a slight, though not significant, tendency of increasing false positive errors as a function of retention intervals was observed. That was consistent with Cregg (1976)

Table 12

Summary of the analysis of variance

on the reaction-time data of Experiment III

Source	MS	df	SS	F
Subjects (a)	9.618	11	.874	
Movement cues (j)	.044	1	.043	.984
a x j	.487	11	.044	
Retention intervals (k)	1.349	2	.675	3.779*
a x k	3.928	22	.179	
Responses (1)	.189	1	.189	.711
a x 1	2.927	11	.266	
j x k	.032	2	.016	.475
a x j x k	.746	22	.034	
j x 1	.005	1	.005	.174
a x j x 1	.285	11	.026	
k x 1	.417	2	.209	3.087
a x k x 1	1.487	22	.068	
j x k x 1	.027	2	.014	.530
a x j x k x 1[1]	.563	22	.026	

[1] twenty-three degrees of freedom should be substracted from the 22 df of the three-factor error term due to the 23 raw RT that were estimated as a method of replacement of the missing data

*significant at the .05 level

Table 13

Mean reaction time (in msec) for each retention interval condition as a function of the movement cues and the responses required

Retention intervals	Movement cues				
	Distance		End location		
	Positive response	Negative response	Positive response	Negative response	Grand mean
0 sec	688.17	500.33	682.83	421.42	573.19
20 sec unfilled	499.00	531.58	527.67	512.83	517.77
20 sec filled	793.08	764.42	699.00	724.08	745.15
Grand mean	660.08	598.78	636.50	552.78	
Grand mean	629.43		594.64		612.03

concerning the retention interval effects and with results from Experiment I as far as memory load was concerned. In Experiment I, load was imposed on memory by means of the number of movements stored in while in Experiment III, loads corresponded to the difficulty of the retention interval. While the trend was significant in Experiment I, it was not in this third experiment probably due to the much lower error rate observed.

Reaction-time data. In this experiment, movement information have been found to be rehearsable (i.e. recognition latencies were unaffected by an unfilled retention interval). Clifton and Birenbaum (1970) also found with digits that unfilled retention intervals of from .8 to 4.8 sec did not affect recognition RT for positive and negative responses. Contrary to the results of Experiment III, Marshall (1972) found a significant increase in recognition errors of movement information as a function of unfilled retention intervals. However he investigated the effects of much longer retention intervals, namely 5, 60, and 90 sec. Kantowitz (1974) also found a significant increase in recognition errors of movement information from immediate recognition to recognition after a 20 sec unfilled retention interval. Results from Marshall (1972) and Kantowitz (1974) were thus not replicated neither in terms of recognition errors nor in terms of recognition RT.

In this experiment EL information has been found to be unaffected by an unfilled retention interval but affected by an interpolated, attention-demanding, task which is in agreement with studies on delayed reproduction of E-defined movements (Keele & Ells, 1972; Laabs, 1973, 1974). On the other hand, D information has also been found unaffected

by the unfilled retention interval which is in agreement with results reported by Diewert (1975) but in desagreement with most studies on delayed reproduction of E-defined movements (Posner, 1967b; Laabs, 1973, 1974). Furthermore, D information was affected by the interpolated task which is in desagreement with Posner and Konick (1966), Posner (1967b), Laabs (1973), and Diewert (1975) concerning delayed reproduction of D information. From Experiment III it could be concluded that D and EL have identical retention characteristics.

Taken collectively, results of Experiment I, II, and III, in which E-defined movements were used, indicate that EL and D information would have identical encoding and retention characteristics. Such point of view would be in desagreement with most studies on reproduction of E-defined movements (Marteniuk & Roy, 1972; Keele & Ells, 1972; Laabs, 1973, 1974; Stelmach & Kelso, 1973; Diewert, 1975). However that point of view would be in agreement with studies on reproduction of S-defined movements concerning the equivalence of the retention characteristics of D and EL information (Marteniuk, 1973; Jones, 1974), although those and other studies in that area have usually found more efficient encoding processes for EL relative to D information (Marteniuk, 1973; Stelmach _et al_, 1975).

One problem remains unsolved and refers to the question of whether perceptual or conceptual codes were stored in the motor short-term store and searched for during the retrieval process. The perceptual code might refer to the representation of the movement _per se_ and as we said previously (p. 42), would be specified in terms of a set of features (D, SL, EL) within the particular modality. The conceptual code on the other hand might refer to either the inter-modality

representation of a distance, a specific location in space, or perhaps of the total movement <u>per se</u>. The question of whether unitary perceptual codes for a given movement or different conceptual codes associated with that movement were stored in STMM remains unanswered.

Perhaps with the exception of Experiment I, the tasks in Experiment II and III were probably simple enough to necessitate the encoding at the level of a perceptual code only. As noted by Atkinson <u>et al</u> (1974):

> "a greater readiness to classify on the basis of perceptual factors than on other (conceptual) factors is consistent with the model. Since a test stimulus will be represented in the memory system as a perceptual code before it can be represented as a conceptual code, strategies that allow accurate responding by processing perceptual codes will be preferred in those tasks where response speed is an important task demand". (p. 134)

Unlike a reproduction accuracy task in which response speed is not important, the task that was used here placed a great emphasis upon response speed. This emphasis may have forced the Ss to process the information at the level of a perceptual, modality specific, code. Therefore the use of a unitary perceptual code for a given movement may explain the equivalence of recognition based upon D and EL cues, and consequently the identical encoding and memory characteristics observed for both cues.

One interesting series of experiments to be undertaken in the area of motor recognition memory would be one in which Ss would be forced to process information at the level of conceptual codes. In this way, inter-modality information could be manipulated or categories of movement information (e.g. short movement) could be asked to be recognized. This would be a means of comparing recognition latencies of movement information encoded at different levels of complexity.

Chapter 5

GENERAL DISCUSSION AND CONCLUSIONS

General discussion

The purpose of this series of experiments was to explore the recognition processes in short-term motor memory. Three reasons were offered in support of the choice of a recognition paradigm to analyse short-term motor memory. The first one was that motor recognition is a major learning task *per se* and deserved to be studied. The second reason was that recent models of motor performance have posited an important recognition mechanism but remained quite silent as to processes involved. The last reason was that a recognition paradigm can sometimes be very sensitive to encoding and storage processes in short-term motor memory. A very limited number of studies was found in the literature that investigated motor recognition memory and thus the need was felt for this series of experiments.

The task consisted of simple, linear, positioning movements (left to right abduction of the right arm in the horizontal plane), using a metal track and a slider moving freely along the track. Each trial was composed of two parts. In the first part, the subject was presented a movement to be memorized. In the second part, following a fixed delay, the subject was presented a test movement. Immediately upon termination of the test movement, the subject had to respond as rapidly as he could by pressing one of two keys, whether or not the test movement was the one he had previously memorized.

If it was, he made a positive response by pressing one of two keys. Otherwise he made a negative response by pressing the other key.

Recognition latency was defined as the time that elapsed from termination of the test movement to the key-pressing response. Recognition latencies from only correct positive and correct negative responses were analyzed. Percentage of response errors (false positive and false negatives) were also analyzed.

The purpose of the first experiment was to determine the effects of the number of movements in memory (i.e. the memory-set size effect) on the recognition process of movement information and particularly on the recognition process of three specific cues of a movement along with a control condition. The three movement cues were: (a) the starting location, (b) the end location, and (c) the distance of a memorized movement. The control condition was the recognition of a memorized movement as a whole. That is to say the starting locations, the end locations and the distances of both the memorized movement and the test movement were identical in all respect.

An overall error rate of 39.01% was obtained. With such a high error rate and possibly speed-accuracy trade-offs embodied in both types of dependent variables, it was felt that recognition RT was not any more a sensitive and reliable measure of the processes under scrutiny. As a matter of fact, all main effects and interactions failed to reach the $\alpha = .05$ level of significance in the analysis of variance of the RT data. Recognition error was thus considered to be the main dependent variable.

Concerning recognition errors, results obtained parralled those obtained from recall paradigms: performance was a direct function of

memory load. In terms of the present experiment, it meant that recognition errors were linearly related to memory set size. Concerning movement cues, only one cue was found to be significantly different than the other cues: starting location. In fact, subjects committed significantly more errors when recognizing starting location information relative to the other two movement cues (distance and end location) and relative to the control condition (distance-plus-location information). Finally, it was also found that the increase in recognition errors as a function of memory set size was mostly due to an increase in false positive errors, a finding repeatedly reported in the verbal memory literature.

In this first experiment a postcuing technique was employed. That is to say, subjects were instructed as to which cue was going to be tested only after the movement (or movements) was (were) memorized. It was felt that such technique was perhaps responsible, at least in part, for the relatively high error rate observed.

The purpose of the second experiment was therefore to determine the effects of the locus of instruction to cue on specific attributes of movements. Two conditions were compared. A precuing condition in which the attribute to be recognized was indicated before the to-be-memorized movement was presented, and a postcuing condition in which the attribute was indicated after the presentation of the to-be-memorized movement. As in Experiment I, three specific attributes or movement cues were tested along with a control condition. The cues were the starting location, the end location, or the distance of the memorized movement. The control condition was the recognition of the memorized movement as a whole.

Again, as in Experiment I, the overall error rate was relatively high (25.39%) and the analysis of variance on the RT data revealed no systematic effects. The RT data, as in Experiment I, have to be interpreted very cautiously due to the error rate.

Concerning recognition errors, no differences were found between the two loci of instructions. Therefore, it can be concluded that the postcuing technique employed in Experiment I was probably not responsible for the error rate of that experiment. Again, as in Experiment I, there were no significant differences in terms of errors between distance-plus-location, distance, and end-location information with starting-location information manifesting the highest recognition error rate.

The purpose of the third experiment was to determine the effects of three retention conditions: (a) immediate recognition, (b) recognition after an unfilled 20 sec retention interval, and (c) recognition after a 20 sec retention interval filled with an attention-demanding task. Only two movement cues were compared, distance and end location. Those were selected on the basis of their apparent encoding similarities observed in Experiment I and II.

By rendering the memory and the test movement more dissimilar in this third experiment, the error rate was in fact decreased to 15.97% with no significant differences, in terms of recognition errors, among the different experimental conditions. With these results in mind, it was expected that recognition RT was therefore more sensitive to the effects, if any, of the independent variables than it was in the first two experiments. As a matter of fact, one main effect came out significant and that was the retention interval main effect. It was found that recognition RT of both distance and end-location information were

left unaffected by the unfilled retention interval but lengthed by the retention interval filled with an interpolated task. In addition to the fact that the movement cue main effect was not significant and the absence of a significant movement cue by retention interval interaction it was concluded that both distance and end-location information had identical retention characteristics.

Two major methodological problems associated with this type of paradigm will have to be resolved before solid conclusions can be reached concerning recognition processes in short-term motor memory. The first one has to do with the difficulty of the recognition task and the second one with the form of presentation of the stimulus material.

Concerning the difficulty of the recognition task, a difference of 3 cm was adopted in Experiment I between a memory movement and its distractor (see: Appendix A for the rational behind this choice). That is to say, when the movements to be memorized had amplitudes of 1, 7, or 13 cm, the distractors used to call negative responses had amplitudes of 4, 10, and 16 cm respectively. For Experiment III, the difference was set at 6 cm. When memorized movements had amplitudes of 1, 4, or 13 cm, distractors had amplitudes of 7, 10, and 19 cm respectively.

While differences adopted for Experiment I were already above just-noticeable-differences for these types of stimuli (see: Appendix A) they still resulted in an overall error rate of 39.01%. While these differences were still increased in Experiment III, the overall error rate was relatively high with a 15.97%. In future experiments, the overall error rate will have to be reduced by increasing even more the differences between memory and distractor movements and by giving extensive practice to the subjects.

The second methodological problem has to do with the form of presentation of the stimulus material when memory set size is a factor of interest. When this paradigm is used with verbal material (e.g. digits, letters, words, and so forth), the to-be-memorized information are presented simultaneously, usually by means of a tachistascope. Test information can thus be presented very shortly afterwhile. In Experiment I, to-be-memorized movements were presented sequentialy. Due to the apparatus and the experimental setting, it took approximately 40 sec between the presentation of the first movement to be memorized and the presentation of the test movement when three movements had to be memorized. It is possible then that the test movement was being compared with already degraded representations of memory movements and that set size effect be completely confounded with time or decay effects. In future experiments, care should be exercised such that presentation of the memorized movements be simultaneous or be as closed in time as possible.

Conclusion

1. Despite an overall error rate somewhat higher than that normally reported in the verbal memory literature, results from recognition latencies in same cases (e.g. Experiment III) and recognition errors in some other cases (e.g. Experiments I and II) paralleled those from several studies in the verbal and motor memory literature. It can reasonnably be concluded that a motor recognition paradigm, allied to recognition latency as the main dependent variable, is a viable tool of investigation into short-term motor memory, provided that the overall error rate is at least inferior to 16% and preferably lower.

2. Distance, end location, and distance+location information do appear to have identical encoding and retention characteristics into short-term motor memory in as far as recognition errors are concerned (e.g. Experiment I and II). Furthermore, distance and end-location information do appear to have identical encoding and retention characteristics as far as recognition latencies are concerned (e.g. Experiment III). From results of Experiment III, it can also be concluded that it takes as much time to recognize distance as it takes to recognize end-location information.

3. Starting location appeared to be the most difficult cue to encode (e.g. Experiment I and II). Whether it is a valid observation or is a result of an artifact from the procedure to evaluate recognition of this type of cue will have to be verified in future experiments.

4. Whether the movement cues to be recognized are indicated prior to or after the memorization of the movement does not seem to affect the error rate at the time of recognition.

5. Due to error rates observed and especially to error rate of Experiment I, no conclusions can be reached concerning the modes of operations of the recognition process into short-term motor memory, whether the process is serial or not, exhaustive or not, and whether there is a search at all of the content of the short-term motor memory storage system.

6. Recognition errors appeared to be a linear function of memory set size largely due to an increase in false positive errors as a function of set size. That is to say, as memory set size is increased, a greater tendancy to recognize a distractor as a memory movement is manifested.

7. It takes as much time to recognize a movement as the correct one, or one that has been experienced before as it takes to recognize a movement as the incorrect one, or one that was used as a distractor (e.g. Experiment III).

Bibliography

Adams, J. A. A closed-loop theory of motor learning. Journal of Motor Behavior, 1971, 3, 111-150.

Adams, J. A. & Dijkstra, A. Short-term memory for motor responses. Journal of Experimental Psychology, 1966, 71, 314-318.

Adams, J. A., Marshall, P. H., & Goetz, E. T. Response feedback and short-term motor retention. Journal of Experimental Psychology, 1972, 92, 92-95.

Anders, T. R., Fozard, J. L., & Lillyquist, T. D. Effects of age upon retrieval from short-term memory. Developmental Psychology, 1972, 6, 214-217.

Atkinson, R. C., Herrmann, D. J., & Wescourt, K. T. Search processes in recognition memory. In R.L. Solso (Ed.), Theories in cognitive psychology: The Loyola symposium. Potomac, Maryland: Lawrence Erlbaum Associates, 1974, 101-146.

Atkinson, R. C., & Juola, J. F. Search and decision processes in recognition memory. In D.H. Krantz et al, (Eds.), Contemporary developments in mathematical psychology: Learning, memory and thinking. San Francisco: W. H. Freeman, 1974.

Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In K.W. Spence & J.T. Spence (Eds.), The psychology of learning and motivation (Vol. 2). New York: Academic Press, 1968.

Baddeley, A. D., & Ecob, J. R. Reaction time and short-term memory: Implications of repetition effects for the high-speed exhaustive scan hypothesis. The Quarterly Journal of Experimental Psychology, 1973, 25, 229-240.

Bower, G. A multi-component theory of the memory trace. In K.W. Spence & J.T. Spence (Eds.), The psychology of learning and motivation (Vol. 1). New York: Academic Press, 1967, 229-325.

Briggs, G. E., & Blaha, J. Memory retrieval and central comparison times in information processing. Journal of Experimental Psychology, 1969, 79, 395-402.

Briggs, G. E., & Swanson, J. M. Encoding, decoding, and central functions in human information processing. Journal of Experimental Psychology, 1970, 86, 296-308.

Burrows, S., & Okada, R. Serial position effects in high speed memory search. Perception and Psychophysics, 1971, 10, 305-308.

Clifton, C., & Birenbaum, S. Effects of serial position and delay of probe in a memory scan task. Journal of Experimental Psychology, 1970, 86, 69-76.

Clifton, C., Cruse, D., & Gutschera, K. D. Recoding processes in recognition: Some effects of presentation rate. Memory and Cognition, 1973, 1, 387-394.

Clifton, C., & Tash, J. Effect of syllabic word length on memory search rate. Journal of Experimental Psychology, 1973, 99, 231-235.

Colby, M. The effect of separate encoding processes on the same motor pattern. Paper presented at the 6th Canadian Symposium for Psychomotor Learning and Sport Psychology. Halifax, 1974.

Connolly, K., & Jones, B. A developmental study of afferent-reafferent integration. British Journal of Psychology, 1970, 61, 259-266.

Corballis, M. C., Kirby, J., & Miller, A. Access to elements of a memorized list. Journal of Experimental Psychology, 1972, 94, 186-190.

Corballis, M. C., & Miller, A. Scanning and decision processes in recognition memory. Journal of Experimental Psychology, 1973, 98, 379-386.

Corcoran, D. W. D. Pattern recognition. Harmondsworth: Penguin Books, 1971.

Cregg, V. Word frequency recognition and recall. In J. Brown (Ed.), Recall and recognition. New York: J. Wiley & Sons, 1976, 183-216.

Craik, F. I. M., & Lockhart, R. S. Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 671-684.

Cruse, D., & Clifton, D. Recoding strategies and the retrieval of information from memory. Cognitive Psychology, 1973, 4, 157-193.

Dardley, C. F., Klatsky, R. L., & Atkinson, R. C. Effects of memory load on reaction time. Journal of Experimental Psychology, 1972, 96, 232-234.

Diewert, G. L. Retention and coding in motor short-term memory: A comparison of storage codes for distance and location information. Journal of Motor Behavior, 1975, 7, 183-190.

Egeth, H., Marcus, N., & Bevan, W. Target-set and response-set interactions: Implications for models of human information processing. Science, 1972, 176, 1447-1448.

Forrin, B., & Morin, R. E. Recognition time for items in short- and long-term memory. Acta Psychologica, 1969, 30, 126-141.

Foss, D. J., & Dowell, B. E. High-speed memory retrieval with auditorily presented stimuli. Perception & Psychophysics, 1971, 9, 465-468.

Galanter, E. H. In D.P. Kimble (Ed.), The organization of recall Vol. 2. New York: The New York Academy of Sciences, 1967.

Gentile, A. M. Research in short term motor memory: Methodological mire. In M.G. Wade & R. Martens (Eds.), Psychology of motor behavior and sport. Urbana, Ill.: Human Kinethics Publishers, 1974.

Goodman, D., & Schutz, R. W. The repetition effect in short-term motor memory. Mouvement, Proceedings of the 7th Canadian Psychomotor Learning and Sport Psychology Symposium, 1975, 141-146. (Monograph)

Hagman, J. D., & Francis, E. W. The instructional variable and kinesthetic cue recall. Journal of Motor Behavior, 1975, 7, 141-146.

Hoving, K. L., Morin, R. E., & Konick, D. S. Recognition reaction time and size of the memory set: A developmental study. Psychonomic Science, 1970, 21, 247-248.

Howard, I. P., & Templeton, W. B. Human spatial orientation. New York: John Wiley & Sons, 1966.

Jones, B. Role of central monitoring of efference in short-term memory for movements. Journal of Experimental Psychology, 1974, 102, 37-43.

Juola, J. F., Taylor, G. A., & Young, M. E. Stimulus encoding and decisions processes in recognition memory. Journal of Experimental Psychology, 1974, 102, 1108-1115.

Kantowitz, B. H. Modality effects in recognition short-term motor memory. Journal of Experimental Psychology, 1974, 103, 522-529.

Kausler, D. H. Continuity of processes across variants of recognition learning. In R.L. Solso (Ed.), Theories in cognitive psychology: The Loyola symposium. Potomac, Maryland: Lawrence Erlbaum Associates, 1974, 45-75.

Keele, S. W. Attention and human performance. Pacific Palisades, Calif.: Goodyear Publishing, 1973.

Keele, S. W., & Ells, J. G. Memory characteristics of kinesthetic information. Journal of Motor Behavior, 1972, 4, 127-134.

Kintsch, W. Models for free recall and recognition. In D.A. Norman (Ed.), Models of human memory. New York: Academic Press, 1970.

Klatzky, R. L., Juola, J. F., & Atkinson, R. Test stimulus representation and experimental context effects in memory scanning. Journal of Experimental Psychology, 1971, 87, 281-288.

Klein, R. M., & Posner, M. I. Attention to visual and kinesthetic components of skills. Brain Research, 1974, 71, 401-411.

Kristofferson, M. W. Effects of practice on character-classification performance. Canadian Journal of Psychology, 1972, 26, 540-560.

Laabs, G. J. Cues effects in motor short term memory. Doctoral dissertation, University of Oregon, 1971.

Laabs, G. J. Retention characteristics of different reproduction cues in motor STM. Journal of Experimental Psychology, 1973, 100, 168-177.

Laabs, G. J. The effects of interpolated motor activity on the short-term retention of movement distance and end-location. Journal of Motor Behavior, 1974, 6, 279-288.

Laabs, G. J. Comment on "retention characteristics of motor short-term memory cues". Journal of Motor Behavior, 1975, 7, 147-150.

Levin, I. P., Norman, K. L., & Dolezal, J. M. Response scale effects and integration processes in the averaging of motor movements. Journal of Motor Behavior, 1973, 5, 1-8.

Lively, B. L. Speed accuracy trade-off and practice as determinants of stage duration in memory search task. Journal of Experimental Psychology, 1972, 96, 97-103.

Lively, B. L. Stage independence in a memory search task. Canadian Journal of Psychology, 1973, 27, 77-82.

Marshall, P. H. Recognition and recall in short-term motor memory. Journal of Experimental Psychology, 1972, 95, 147-153.

Marteniuk, R. G. Retention characteristics of motor short-term memory cues. Journal of Motor Behavior, 1973, 5, 249-259.

Marteniuk, R. G. A cognitive information processing model of motor short term memory. In B.S. Rushall (Ed.), The status of psychomotor learning and sport psychology research. Sport Science Associates, 1975. (a)

Marteniuk, R. G. Further considerations of "retention characteristics of motor short-term memory cues", a reply to Laabs. Journal of Motor Behavior, 1975, 7, 151-152. (b)

Marteniuk, R. G. Information processing in motor skills. New York: Holt, Rinehart & Winston, 1976.

Marteniuk, R. G., & Roy, E. A. The codability of kinesthetic location and distance information. Acta Psychologica, 1972, 36, 471-479.

Marteniuk, R. G., Shields, K. W., & Campbell, S. Amplitude, position, timing and velocity as cues in reproduction of movement. Perceptual and Motor Skills, 1972, 35, 51-58.

McCormack, P. D. Recognition memory: How complex a retrieval system. Canadian Journal of Psychology, 1972, 26, 19-41.

McCormack, P. D., & Swenson, A. L. Recognition for common and rare words. Journal of Experimental Psychology, 1972, 95, 72-77.

Miller, J. O., & Pachella, R. G. Locus of the stimulus probability effect. Journal of Experimental Psychology, 1973, 101, 227-231.

Nacson, J., Jacger, M., & Gentile, A. M. Encoding processes in short-term motor memory. In I.A. Williams & L.M. Wankel (Eds.), Proceedings of the Fourth Canadian PMLSP Symposium. University of Waterloo, 1972.

Naus, M. J. Memory search of categorized lists: A consideration of alternative self-terminating search strategies. Journal of Experimental Psychology, 1974, 102, 992-1000.

Newell, A. A theoretical exploration of mechanisms for coding the stimulus. In A.H. Melton & E. Martin (Eds.), Coding processes in human memory. New York: John Wiley & Sons, 1972.

Newell, K. M. Visual flight feedback as a determiner of motor response recognition. Research Quarterly, 1975, 46, 235-242.

Newell, K. M. Motor learning without knowledge of results through the development of a response recognition mechanism. Journal of Motor Behavior, 1976, 8, 209-218.

Newell, K. M., & Boucher, J. L. Motor response recognition: Two processes. Journal of Motor Behavior, 1974, 6, 81-86.

Newell, K. M., & Chew, R. A. Recall and recognition in motor learning. Journal of Motor Behavior, 1974, 6, 245-254.

Nickerson, R. S. The use of binary-classification tasks in the study of human information processing: A tutorial survey. In S. Kornblum (Ed.), Attention and performance IV. New York: Academic Press, 1973.

Pepper, R. L., & Herman, L. M. Decay and interference effects in short-term retention of a discrete motor act. Journal of Experimental Psychology, 1970, 83. (Monograph Suppl. 2).

Peters, G. L. Coding processes in active and inactive memory. Journal of Experimental Psychology, 1974, 102, 423-430.

Pew, R. W. Human perceptual-motor performance. In B.H. Kantowitz (Ed.), Human information processing: Tutorials in performance and cognition. New York: Erlbaum, 1974.

Posner, M. I. Short-term memory systems in human information processing. Acta Psychologica, 1967, 27, 267-284. (a)

Posner, M. I. Characteristics of visual and kinesthetic memory codes. Journal of Experimental Psychology, 1967, 75, 103-107. (b)

Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. Retention of visual and name codes of single letters. In M. Coltheart (Ed.), Readings in cognitive psychology. New York: Holt, Rinehart & Winston, 1972.

Posner, M. I., & Konick, A. F. Short-term retention of visual and kinesthetic information. Journal of Organizational Behavior and Human Performance, 1966, 1, 71-86.

Posner, M. I., & Mitchell, R. F. Chronometric analysis of classification. Psychological Review, 1967, 74, 392-409.

Ratcliff, R., & Murdock, B. B. Retrieval processes in recognition memory. Psychological Review, 1976, 83, 190-215.

Reed, A. V. List length and time course of recognition in immediate memory. Memory and Cognition, 1976, 4, 16-30.

Restle, F. Critique of pure memory. In R.L. Solso (Ed.), Theories in cognitive psychology: The Loyola symposium. Potomac, Maryland: Lawrence Erlbaum Associates, 1974, 203-217.

Roy, E. A. An assessment of the role of preselection in motor short-term memory. A paper presented at the International Congress of Physical Activity Sciences. Quebec City, 1976.

Roy, E. A., & Diewert, G. L. Encoding of kinesthetic extent information. Perception and Psychophysics, 1975, 17, 559-564.

Schmidt, R. A., & White, J. L. Evidence for an error detection mechanism in motor skills: A test of Adams' closed-loop theory. Journal of Motor Behavior, 1972, 4, 143-154.

Schmidt, R. A. A schema theory of discrete motor skill learning. Psychological Review, 1975, 82, 225-260.

Schutz, R. W. A theory of motor response organization and retrieval in choice reaction time tasks. Unpublished doctoral dissertation, University of Wisconsin, 1972.

Shea, J. B. The effects of labeling on motor short-term memory. A paper presented to the 6th Canadian Psychomotor Learning and Sport Psychology Symposium. Halifax, 1974.

Smith, E. E. Choice reaction time: An analysis of the major theoretical positions. Psychological Bulletin, 1968, 69, 77-110.

Sperling, G. Successive approximations to a model of short term memory. Acta Psychologica, 1967, 27, 285-292.

Stelmach, G. E. Short-term motor memory: Have we made any progress. In M.G. Wade & R. Martens (Eds.), Psychology of motor behavior and sport. Urbana, Ill.: Human Kinetics Publishers, 1974.

Stelmach, G. E. & Bruce, J. R. Recall load in STM. Psychonomic Science, 1970, 21, 205-207.

Stelmach, G. E., & Kelso, J. A. Distance and location cues in short-term motor memory. Perceptual and Motor Skills, 1973, 37, 403-406.

Stelmach, G. E., & Kelso, J. A. Memory trace strength and response biasing in STMM. Memory and Cognition, 1975, 3, 58-62.

Stelmach, G. E., Kelso, J. A., & Wallace, S. A. Preselection in short-term motor memory. Journal of Experimental Psychology (Human learning and memory), 1975, 1, 745-755.

Stelmach, G. E., & Walsh, M. F. The temporal placement of interpolated movements in short-term motor memory. Journal of Motor Behavior, 1973, 5, 165-173.

Sternberg, S. High-speed scanning in human memory. Science, 1966, 153, 652-654.

Sternberg, S. Retrieval of contextual information from memory. Psychonomic Science, 1967, 8, 55-56. (a)

Sternberg, S. Two operations in character recognition: Some evidence from reaction-time measurements. Perception and Psychophysics, 1967, 2, 45-53. (b)

Sternberg, S. The discovery of processing stages: Extensions of Donder's method. In W.G. Koster (Ed.), Attention and Performance II. Acta Psychologica, 1969, 30, 276-315. (a)

Sternberg, S. Memory-scanning: Mental processes revealed by reaction time experiments. American Scientist, 1969, 57, 421-457. (b)

Wickelgren, W. A., & Norman, D. A. Strength models and serial position in short term recognition memory. Journal of Mathematical Psychology, 1966, 3, 316-347.

Wilberg, R. B. Response accuracy based upon recall from visual and kinesthetic short-term memory. Research Quarterly, 1969, 40, 407-414.

Wilberg, R. B., & Girouard, Y. On the locus of the range effect in a short-term motor memory paradigm. Mouvement, Proceedings of the 7th Canadian Psychomotor Learning and Sport Psychology Symposium, 1975, 153-158. (Monograph)

Wilberg, R. B., & Salmela, J. H. Information load and response consistency in sequential short term motor memory. Perceptual and Motor Skills, 1973, 37, 23-29.

Williams, H. L., Beaver, W. S., Spence, M. T., & Rundell, O. H. Digital and kinesthetic memory with interpolated information processing. Journal of Experimental Psychology, 1969, 80, 530-536.

Winer, B. J. Statistical principles in experimental design. New York: McGraw Hill, 1962.

Wingfield, A., & Branca, A. A. Strategy in high speed memory search. Journal of Experimental Psychology, 1970, 83, 63-67.

APPENDIX A

STIMULUS MATERIAL

Table 14

Stimulus material for Experiment I:

I. Total set of movements from which memory movements were drawn[1, 2]

Movement features			
Starting location	Distance	End location	Functions for half of the Ss
15	1 cm	16	
18	4 cm	22	memory movement
21	7 cm	28	
24	10 cm	34	memory movement
27	13 cm	40	
30	16 cm	46	memory movement

[1]Those movements are mapped on a linear scale such as a metal track, graded in centimeters, used for linear positioning movements. For example, the first one is meant to represent a movement of 1 cm starting at location 15 and ending at location 16.

[2]The difference between any two distances is 3 cm. This value is well above JNDs since it was found that a difference of 2.5 cm, for a movement length of 17 cm, was sufficient to make this movement length different from any other ones (Tannis, 1972).

Table 14 (continued)

II. Total set of movements from which a test movement was selected depending on the type of cue

Cue	Movement features: Starting location	Distance	End location	Functions for half of the Ss
Distance+ location	15	1 cm	16	negative response
	18	4 cm	22	positive response
	21	7 cm	28	negative response
	24	10 cm	34	positive response
	27	13 cm	40	negative response
	30	16 cm	46	positive response
Distance only	10	1 cm	11	negative response
	10	4 cm	14	positive response
	10	7 cm	17	negative response
	10	10 cm	20	positive response
	10	13 cm	23	negative response
	10	16 cm	26	positive response
End location only	10	6 cm	16	negative response
	10	12 cm	22	positive response
	10	18 cm	28	negative response
	10	24 cm	34	positive response
	10	30 cm	40	negative response
	10	36 cm	46	positive response
Starting location only	10	5 cm	15	negative response
	10	8 cm	18	positive response
	10	11 cm	21	negative response
	10	14 cm	24	positive response
	10	17 cm	27	negative response
	10	20 cm	30	positive response

Table 15

Stimulus material for Experiment II

I. Total set of movements from which a test movement was selected

Cue	Movement features: Starting location	Distance	End location	Functions for half of the Ss
	21	7 cm	28	
	24	10 cm	34	memory movement

II. Total set of movements from which a test movement was selected depending on the type of match

Distance + location	21	7 cm	28	negative response
	24	10 cm	34	positive response
Distance only	10	7 cm	17	negative response
	10	10 cm	20	positive response
End location only	10	18 cm	28	negative response
	10	24 cm	34	positive response
Starting location only	10	11 cm	21	negative response
	10	14 cm	24	positive response

Table 16

Stimulus material for Experiment III

I. Total set of movements from which memory movements were drawn

Movement features			
Starting location	Distance	End location	Functions for half of the Ss
15	1 cm	16	memory movement
21	7 cm	28	
18	4 cm	22	memory movement
24	10 cm	34	
27	13 cm	40	memory movement
33	19 cm	52	

Table 16 (continued)

II. Total set of movements from which a test movement was selected depending on the type of cue

Cue	Movement features			Functions for half of the Ss
	Starting location	Distance	End location	
Distance	10	1 cm	11	positive response
	10	7 cm	17	negative response
	10	4 cm	14	positive response
	10	10 cm	20	negative response
	10	13 cm	23	positive response
	10	19 cm	29	negative response
End location	10	6 cm	16	positive response
	10	18 cm	28	negative response
	10	12 cm	22	positive response
	10	24 cm	34	negative response
	10	30 cm	40	positive response
	10	42 cm	52	negative response

APPENDIX B

INSTRUCTION TO THE SUBJECTS

Written instruction to the subjects of Experiment I

The purpose of this experiment is to analyze the capacity that we have of recognizing a given movement as one that we have already executed in the past. We will first proceed with some practice trials for which the procedure is as follows:

1. You will first execute a movement: in doing so, try to remember three characteristics of that movement: (a) its starting-point in space; (b) the distance covered; (c) its end-point in space, because immediately at the end of the execution of the movement, a test will be administered.

2. The test will be administered in the following manner: you will execute a test movement and at the end, you will have to say, as rapidly as possible, whether the test movement as a whole (i.e. including all three characteristics) <u>or</u> only one of the three characteristics was the same as in the first movement.

For example, the experimenter may ask you: "tell me if the distance that will be covered in the next test movement is the same as the one you have covered in the movement just executed". If so, at the end of the test movement, press as fast as you can the key "yes". Otherwise, press as fast as you can the key "no".

Therefore, the experimenter can ask you four questions: (a) is the next test movement as a whole the same as the one just executed? (b) is the distance of the next test movement the same as the one of the movement just executed? (c) is the starting-point the same as the one of the movement just executed? and (d) is the end-point the same as the one of the movement just executed.

The experiment will be composed of an equal number of trials for which the correct answer will be "yes" and of trials for which the correct answer will be "no". Do not forget that what will be important is the speed of a correct answer.

We will now proceed with some practice trials. If you have any questions following that, do not hesitate to ask them. Good luck.

APPENDIX C

COMPLEMENTARY DATA AND ANALYSES

Table 17

Linear trend analyses of recognition errors

as a function of memory set size (Experiment I)

I. Memory set size main effect

Source	SS	df	MS	F
Linear trend	2.000	1	2.000	25.31**
Residual	1.741	22	.079	

II. Interaction between memory set size and types of responses

Source	SS	df	MS	F
Linear trend	1.535	1	1.535	5.991*
Residual	5.630	22	.256	

* significant at the .05 level
** significant at the .01 level

Table 18

Linear trend analysis of recognition RT

as a function of memory set size (Experiment I)

Source	SS	df	MS	F
Linear trend	.361	1	.361	2.344
Residual	3.386	22	.154	

Table 19

Tukey (a) tests applied to differences between means of percent recognition errors for memory set size and movement cues (Experiment I)

	Memory set size (M)			
	M = 1	M = 2	M = 3	
Means	32.99	39.23	44.79	
32.99		6.24*	11.80**	Minimum difference of 5.89 at $\alpha = .05$ and 7.60 at $\alpha = .01$
39.23			5.56	

* significant at the .05 level
** significant at the .01 level

	Movement cues[1]				
	D+L	D	EL	SL	
Means	29.17	37.50	37.04	52.32	
29.17		8.33	7.87	23.15**	Minimum difference of 10.70 at $\alpha =$ .05 and 13.38 at $\alpha = .01$
37.50			0.46	14.82**	
37.04				15.28	

[1] D+L Distance+location; D Distance; EL End location; SL Starting location

** significant at the .01 level

Table 20

Tukey (a) test applied to differences between means of percent recognition errors for movement cues (Experiment II)

	Movement cues[1]				
	D+L	D	EL	SL	
Means	10.94	28.13	20.31	42.19	
10.94		17.19	9.37	31.25**	Minimum difference of 22.34 at α = .05 and 27.65 at α = .01
28.13			7.82	14.06	
20.31				21.88	

[1] D+L = Distance+location; D = Distance; EL = End location; SL = Starting location

** significant at the .01 level

Table 21

Tukey (a) test applied to differences between means of recognition reaction time for the retention interval conditions (Experiment III)

	Retention interval conditions			
	0 sec	20 sec unfilled	20 sec filled	
Mean	573.19	517.77	745.15	Minimum difference of 217.09 at $\alpha = .05$
573.19		55.42	171.96	
517.77			227.38*	

* significant at the .05 level

TYPED BY MRS LOUISE ST.LOUIS